Comprehensive Truck Size and Weight Limits Study

November, 2013

Bridge Structure Comparative Analysis

Final Draft Desk Scan

U.S. Department of Transportation
Federal Highway Administration

FINAL DRAFT DESK SCAN

1.0 INTRODUCTION

The purpose of the Bridge Task Desk Scan is to provide research and literary technical support provided by various educational and industry supported institutions in the United States, Canada, Australia and Europe the methods and means used in this Comprehensive Truck Size and Weight (CTSW Study) Study's Bridge Desk Scan. The primary intent is to unearth any resources that may inform as to new approaches or refinements to existing approaches to: 1) the quantifying of structural demands on bridges due to 'heavy' truck loads; and/or 2) the derivation of resulting bridge capital costs. The process then involves an assessment as to the relevance and applicability of those approaches to this study.

This report will be organized as follows:

- First a list identifying agencies from which literary technical support has been gained through research, ongoing studies and practice;
- Second a list of documents reviewed. For each document we provide:
    - Title
    - Web Link (if available)
    - Summary (or Abstract) of goals and findings
    - Discussion of relevance to one of CTSW Study topics (as provided in Bridge Sub-Task Project Plan) in *Italic print*

The documents are organized by topic as follows:

GENERAL REFERENCE MANUALS
BRIDGE ASSET MANAGEMENT
BRIDGE DECKS
BRIDGE INVENTORY
DETERIORATION MODEL
FATIGUE
FREIGHT & MODAL SHIFT
COST ALLOCATION STUDIES
    CAS BY STATE
    CAS METHODS AND METHODOLOGY
TRUCK SIZE & WEIGHT STUDIES BY STATE
TRUCK TRAFFIC DATA

2.0 LIST OF AGENCIES

2.1 National Academy of Sciences

TRB – Transportation Research Board
National Cooperative Highway Research Program - NCHRP
Strategic Highway Research Program - SHRP 2
Conferences: International Bridge Conference, IBC

2.2 Federal & State Transportation Agencies

United States Department of Transportation (USDOT)
Federal Highway Administration (FHWA)
Turner Fairbanks Research Center
Long Term Bridge Performance

Arizona – ADOT
California-CalTrans
Illinois - IDOT
Indiana – INDOT
- Joint Transportation Research Program (JTRP)

Kentucky – KDOT
- Kentucky Transportation Cabinet

Louisiana – LDOT
- Louisiana Transportation Research Center

Maryland – MDTA (MD SHA)
Michigan- MDOT
Minnesota – (MnDOT)
Nevada - NVDOT
New York
- NYSDOT, NYCDOT

Ohio - ODOT
Oregon – ODOT
Tennessee – TDOT
Texas – TXDOT
Vermont – VAT
Washington DC – District DOT
Wisconsin – WisDOT

2.3 Universities

Carnegie-Mellon University
Case Western Reserve University
City University of New York
Louisiana Tech University
Lehigh University
Purdue University

University of Kentucky
University of Texas (Austin)
City University of New York (CUNY)
University of Leeds (Coordinator of CATRIN Study)

2.4 Industry Standards & Publications

AASHTO - American Association of State Highway Transportation Officials
ASCE – American Society of Civil Engineers
  Journal of Bridge Engineering
AISC - American Institute of Steel Construction
  (NSBA) National Steel Bridge Alliance
ACI - American Concrete Institute
PCI – Precast Concrete Institute

2.5 Foreign Resources

Canada – Transportation Association of Canada
UK - English Highway Agency
European Transport Commission:
  (**C**ost **A**llocation of **TR**ansit **In**frastructure, **CATRIN**)
  (**UNI**fication of Accounts and Marginal Costs for **T**ransport **E**fficiency, **UNITE**)
  (**G**eneralization of **R**esearch on **A**ccounts Cost **E**stimation, **GRACE**)
  Dutch Ministry of Transport
  Poland:
    General Directorate of National Roads (GDDKiA)
    Road & Bridge Research Institute (IBDiM)
  Swedish Road Administration (SRA)
Australia:
  Australian Transport Council (ATC)
  National Transport Commission (NTC)
  Australian Road Research Board (ARRB)

3.0 REFERENCES – DOCUMENTS REVIEWED

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
3.1 GENERAL REFERENCE MANUALS		
AASHTO MBE 13	The Manual for Bridge Evaluation, 2nd Edition 2013; American Association of State Highway Transportation Officials https://bookstore.transportation.org/	Load Rating, Posting
This document provides guidelines, rules, and specifications for the inspection and load rating of existing bridges. Owner agencies are required to load rate each of their bridges at least biennially to assure they can carry legal loads. This document provides the basis for assessing the load capacity of these bridges with setting of allowable stresses and load factors, which are function of the bridge material, age and condition. *This will be used as the guiding document for the structural analysis, load rating and posting assessment of the bridges.*		
AASHTO HB 17	Standard Specifications for Highway Bridges https://bookstore.transportation.org/	Load Rating, Posting
This document provides guidelines, rules, and specifications for the design of new bridges and rehabilitation of existing bridges. Moreover, it provides truck and lane design loads such H20 and HS20, wind, snow and seismic load combinations and factors for bridge design *This will be used as a supplemental guiding document for the structural analysis, load rating and posting assessment of the bridges. The AASHTO defined rating trucks such as the H20 and HS20 are defined in this manual. These trucks will be used in the ABrR (VIRTIS) program and will be used in part as a basis for evaluating the bridges for their capacity to carry the existing fleet and the proposed future fleet of vehicles.*		
NCHRP Report 575	Legal Truck Loads and AASHTO Legal Loads for Posting, Lichtenstein Consulting Engineers, Inc.; Bala Sivakumar , 2006 http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_575.pdf	Load Rating
Summary: In the US trucks are allowed unrestricted operation on the nations highways' and generally considered legal provided they meet the weight guidelines of the Federal Bridge Formula B (FBF), up to 80,000 lbs. GVW and any if any single axle load does not exceed 20,000 lbs. and tandem axles cannot exceed 34,000 lbs. (Each state has additional guidelines and restrictions.) The current AASHTO truck design loads consisting of the H20 & HS20 family of trucks do not adequately represent the fleet of trucks that operate in the United States. It has been found that on certain bridges, the FBF compliant trucks may overstress those bridges by as much as 22%. One of the goals of Report 575 was to investigate through state surveys and WIM data a representative set of trucks that would more adequately represent the class of trucks that are currently operating and attempt to formulate new design guidelines. Another goal, as stated in the report, was to provide load factors for use with the Load Resistance Factor Design (LRFD) method of design and the Load Resistance Factor Rating LRFR method of load rating. *The NCHRP Report 575 goes to the heart of the Comprehensive Truck Size and Weight Limits Study (CTSW Study) as it relates to structural impacts on bridges and load postings. It was designed to answer the question of "What is the structural effect of the current fleet of legal vehicles on the*		

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
nation's bridges?" However, we found that the report answers this question on "a set of generic spans". Therefore the results and finding of this study could not be wholly inclusive of Steel Trusses and Girder Floor-beam type spans.		
CTSW 2000 Volumes 1 -4	Comprehensive Truck Size and Weight Study: Volume 1 Summary Report; Volume 2 Issues and Background; Volume 3 Scenario Analysis; Volume 4 Guide to Documentation; Multiple Documents; USDOT – Office of Transportation Policy Studies http://www.fhwa.dot.gov/policy/otps/truck/finalreport.htm	Historical Context & Commentary

The Comprehensive Truck Size and Weight Study began in 1994 along with a companion study, the Federal Highway Cost Allocation Study that was submitted to Congress in August, 1997.
The objectives of the 2000 Comprehensive Truck Size and Weight (2000 CTSW) Study were to:
(1) Identify the range of issues impacting TS&W considerations;
(2) Assess current characteristics of the transportation of various commodities including modes used, the predominant types of vehicles used, the length of hauls, payloads, regional differences in transportation characteristics, and other factors that affect the sensitivity of different market segments of the freight transportation industry to changes in TS&W limits; and
(3) Evaluate the full range of impacts associated with alternative configurations having different sizes and weights.
The document forms a historical basis for the current CTSW Study and a basis for understanding on going issues with respect to trucks and bridges. Some of the goals were common with the CTSW Study, however many of the bridge related studies were designed to answer a different question. The effort did not conduct a bridge cost allocation study. A Highway Cost Allocation Method that included a modified "Incremental" method along with several interlinked spreadsheets had been introduced in 1997. This was called the Federal Incremental Method. Neither a nationwide nor regional bridge allocation study was provided, although some local examples of bridge allocation studies were included. In 2003 the Federal Bridge Cost Allocation Method was re-introduced in NCHRP Report 495 (See Reference under sub section ***3.8.2 Cost Allocation Methods*** *below.) Based on our research, a true national bridge cost allocation has not been done.*

3.2 BRIDGE ASSET MANAGEMENT

The topic of bridge asset management was included to highlight a series of topics germane to the study that includes state policies toward the maintenance and preservation of bridges. First, what are the tools that state agencies use (such as PONTIS and Bridge Management Systems) for asset management? Secondly, what decision making process is used for preserving, retrofitting or replacing bridges? Thirdly, what is included or excluded in their budgets? Ultimately we are interested in the bridge costs that the proposed future fleet of trucks will have on the nation's bridges.
The link to the ***FHWA Long Term Bridge Performance (LTBP)*** *web site and publications were included for this study. There is an apparent paradigm in thinking and philosophy that is occurring in light of the nation's aging bridges. In the past 100 years or so, bridges have been built with a planned life span of 75 years. What design standards do we use for trucks that have not yet been conceived and how will these bridges be designed and constructed to meet future needs for an extended life cycle? It's an interesting question, since we are attempting to address a similar issue with regard to bridges that are in service now, how will they perform under the load of a different set of vehicles?*
Another issue that has been raised with regard to bridge preservation and maintenance costs: as indicated by NCHRP Synthesis Report 397, each state has its own unique set of practices and cost factors that are tracked. How can this data be used to make comparisons between states that allow heavier vehicles vs. those that do not. Is it even possible to draw such conclusions? In a greater context can these costs be collected in a standardized way to conduct a national cost allocation study?

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
FHWA-IF-05-040	Transportation Asset Management Case Studies; Office of Asset Management http://www.fhwa.dot.gov/infrastructure/asstmgmt/bmcs701.cfm	Bridge Management PONTIS
This document is a case study covering several states that use the AASHTOWare PONTIS software (initially developed by FHWA) in their asset management practices.		
FHWA - IF - 11-016	Framework for Improving Resilience of Bridge Design; Turner Fairbanks Transportation Research Center, Long Term Bridge Performance http://www.fhwa.dot.gov/bridge/pubs/hif11016/hif11016.pdf	Long Term Bridge Performance
This document provides a framework for bridge engineers to design and build more robust and resilient bridges that are resistant to the forces of nature as well as to the ever growing truck numbers and sizes that frequent the nation’s highways.		
FHWA-HRT-11-037	FHWA LTBP Workshop to Identify Bridge Substructure Repairs; Turner Fairbanks Transportation Research Center, Long Term Bridge Performance http://www.fhwa.dot.gov/publications/research/infrastructure/structures/ltbp/11037/index.cfm	Long Term Bridge Performance
The purpose of this workshop was to consider overall bridge performance and identify geotechnical performance metrics that may correspond to good and poor performance. This report describes the results of the workshop and presents them in the larger perspective of designing and implementing the LTBP program. This document will be of interest to engineers who research, design, construct, inspect, maintain, and manage bridges as well as to decision makers at all levels of management of public highway agencies.		
NCHRP SYN 397	Bridge Management Systems for Transportation Agency Decision Making; 2009; Markow, Michael J.; Hyman, William A.; http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_397.pdf	Bridge Management
The objective of this synthesis study has been to gather information on current practices that agency chief executive officers and senior managers use to make network-level investment and resource allocation decisions for their bridge programs, and to understand how they apply their agency’s bridge management capabilities to support these decisions. The following areas of planning, programming, and performance-based decision making have been addressed. Condition and performance measures that are used to define policy goals and performance targets for the bridge program are: • Methods of establishing funding levels and identifying bridge needs • Methods and organizational responsibilities for resource allocation between the bridge program versus competing needs in other programs (pavement, safety, etc.) • Methods of allocation among districts and selection and prioritization of projects • The role of automated Bridge Management Systems (BMS) in planning, programming, resource allocation, and budgeting • Use of economic methods in bridge management • Methods to promote accountability and communication of the status of the bridge inventory and the bridge program		
CDOT 2012-4	Deterioration and Cost Information for Bridge Management; Colorado Department of Transportation 2012; Hearn, George; http://www.coloradodot.info/programs/research/pdfs/2012/pontis.pdf/view	Bridge Management, PONTIS
Abstract: • Study 87-60 uses contract bid tabulations and element-level condition records to develop element-level actions, costs for actions, transition probabilities for models of deterioration of bridge elements, and		

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
transition probabilities for improvements to elements due to actions. The information on actions, costs, and transition probabilities input to a Pontis BMS bridge database. • Study 87-60 applies transition probabilities for element deterioration to compute the number of years to possible loss of safety in bridges, and to compute the number of years for inspection intervals. • Study 87-60 examines variations among CDOT regions of costs of actions and of deterioration of elements. • Study 87-60 developed a set of software applications to handle bid tabulations, compute costs of actions, compute transition probabilities, and mediate the steps needed for movement of data into and out of PONTIS BMS.		
USDOT PUB	Bridge Preservation Guide; FHWA Office of Infrastructure; http://www.fhwa.dot.gov/bridge/preservation/guide/guide.pdf	Bridge Preservation
This guide provides bridge related definitions and corresponding commentaries, as well as the framework for a systematic approach to a preventive maintenance (PM) program. The goal is to provide guidance on bridge preservation.		
3.3 BRIDGE DECKS *References in this section were selected to address specific issues or were general informational topics relating to bridge decks. The first several reports refer to bridge deck durability, methods for preserving decks including different overlay methods and materials, design of orthotropic steel decks, non-destructive testing of reinforced concrete decks, and a few articles on causes of cracking in reinforced concrete decks whether they be caused by construction (early stripping of forms, improper curing, shrinkage), environment (temperature, rain, snow followed by application of de-icing salts) and/or load induced by vehicles and trucks. An effort is made to understand that initial cracking in bridge decks may not be necessarily caused just by vehicles and trucks, but by other means. However, the eventual development of cracks and other deterioration can be partially attributed to the traveling vehicles (i.e. load) on the bridge deck.* *An important reference for bridge decks is the **NCHRP Report 495**, **Effect of Truck Weights on Bridge Network Costs**, which is not included herein, but rather in section **3.8.2 Cost Allocation Methods** This report describes an approach for evaluating reinforced concrete bridge decks for concrete fatigue as it relates to cost allocations studies. However, a very detailed section is provided on describing the deck deterioration mechanism and ties the failure point of decks to the ultimate shear strength of the deck. (Based on independent studies conducted by Matsui et al at Osaka University Japan 1992 & by Perdicaris at Case Western Reserve University 1993).*		
FHWA-ICT-12-003	Superiority & Constructability of Fibrous Additives for Bridge Deck Overlays, Alhassan, Mohammad A, Ashur, Soleiman A, Indiana-Purdue University Fort Wayne; Illinois Center for Transportation; Illinois Department of Transportation http://www.ict.illinois.edu/publications/report%20files/FHWA-ICT-12-003.pdf	Bridge Decks, Durability, Life Cycle Analysis
This project outlined critical issues essential for successful and durable overlay applications with minimal cracking and delamination. Various micro- and macro-fiber combinations were added to the fibrous overlay mixtures, resulting in 13 fibrous mix designs (nine Latex Modified Concrete, two Micro Silica Concrete, and two Fly Ash Concrete). For further evaluation of the constructability of fibrous overlay—taking into consideration actual field conditions—demonstration bridges were selected and received fibrous overlays through actual IDOT contracts. Life-cycle cost analyses were also conducted to assess potential savings from incorporating fibrous additives within the concrete overlays. This research is pioneering, in terms of using fibrous FAC overlay, which is a potentially sustainable overlay system for preserving bridge decks with lower cost and minimized adverse environmental impact.		
FHWA-IF-12-	Manual for Design, Construction, and Maintenance of Orthotropic Steel	Orthotropic Steel

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<tr><th>DOCUMENT No.</th><th>DOCUMENT TITLE & LINK</th><th>RELEVANCE TO STUDY</th></tr>
<tr><td>027</td><td>Deck Bridges; 2012, Conner, Robert, Fisher, John, et al
http://www.fhwa.dot.gov/bridge/pubs/if12027/if12027.pdf</td><td>Decks</td></tr>
<tr><td colspan="3">This Manual covers the relevant issues related to orthotropic steel deck bridge engineering, including analysis, design, detailing, fabrication, testing, inspection, evaluation, and repair. It includes a discussion of some the various applications of orthotropic bridge construction to provide background with case study examples. It also provides basic criteria for the establishment of a cost-effective and serviceable orthotropic bridge cross section with detailing geometry that has been used on recent projects worldwide. The manual covers both the relevant information necessary for the engineering analysis of the orthotropic steel bridge and the requirements for complete design of orthotropic steel bridge superstructures. Additionally, design details such as materials, corrosion protection, minimum proportions, and connection geometry are addressed as well as basic fabrication, welding, and erection procedures. Portions of the manual also cover methods for maintaining and evaluating orthotropic bridges, including inspection and load rating. Wearing surfaces are also covered in depth. The culmination of all the information is demonstrated in two design examples.</td></tr>
<tr><td>NCHRP SYN 425</td><td>Waterproofing Membranes for Concrete Bridge Decks; Prepared by Russell, Henry G. for AASHTO
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_425.pdf</td><td>Bridge Decks</td></tr>
<tr><td colspan="3">The objective of this synthesis is to update NCHRP Synthesis of Highway Practice 220: Waterproofing Membranes for Concrete Bridge Decks on the same topic published in 1995. This synthesis documents information on materials, specification requirements, design details, application methods, system performance, and costs of waterproofing membranes used on new and existing bridge decks since 1995. The synthesis focuses on North American practices with some information provided about systems used in Europe and Asia.</td></tr>
<tr><td>FHWA/OH-2012/3</td><td>Quantification of Cracks in Concrete Bridge Decks in Ohio District 3; 2012; Sai Ganapuram, Michael Adams, Dr. Anil Patnaik; University of Akron
http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Reports/2012/Structures/134564_FR.pdf</td><td>Bridge Decks, Cracks</td></tr>
<tr><td colspan="3">In this study, a quantitative measurement strategy was adopted by measuring the crack densities of twelve bridges in District 3. Two types of bridges were inspected: three structural slab bridge decks and nine stringer supported bridge decks. Crack densities were determined based on crack maps corresponding to the surveys for each bridge deck. The crack densities determined for the twelve bridge decks indicated that structural slab bridge decks have slightly higher shrinkage crack densities compared to the bridge decks constructed with stringer supports.</td></tr>
<tr><td>SHRP2 S2-R06A-PR1</td><td>Nondestructive Testing to Identify Concrete Bridge Deck Deterioration; Rutgers University – Center for Advanced Infrastructure and Transportation; University of Texas at El Paso; Federal Institute for Materials Research and Testing, BAM Germany; Radar Systems International
http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R06A-RR-1.pdf</td><td>Bridge Decks, ND Testing</td></tr>
<tr><td colspan="3">The ultimate goal of this research was to identify and describe the effective use of NDT technologies that can detect and characterize deterioration in bridge decks. To achieve this goal, the following four specific objectives needed to be accomplished:
1. Identifying and characterizing NDT technologies for the rapid condition assessment of concrete bridge decks;
2. Validating the strengths and limitations of applicable NDT technologies from the perspectives of accuracy, precision, ease of use, speed, and cost;
3. Recommending test procedures and protocols for the most effective application of the promising technologies; and</td></tr>
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DOCUMENT No.	**DOCUMENT TITLE & LINK**	**RELEVANCE TO STUDY**
4. Synthesizing the information regarding the recommended technologies needed in an electronic repository for practitioners		
FHWA/IN/JT RP-2010/04	Control and Repair of Bridge Deck Cracking, Robert Frosch, Sergio Gutuirrez, Jacob Hoffman; Purdue University; Indiana DOT	Bridge Deck Cracking
A large number of bridges across the state of Indiana had exhibited early age deck cracking. This presented a major threat to the bridges' lifespan, as deck cracking often leads to corrosion by creating a path for water and deicing salts to reach the reinforcing steel. Therefore, the need to develop design and construction guidelines to control deck cracking in newly constructed bridges was recognized. In addition, a method to repair deck cracks must be developed to prevent reinforcement corrosion of bridges already in service. The objective of this research was to develop effective design, construction, and repair methods to control bridge deck cracking.		
FHWA/IN/JTR P-2004/10	Interaction Between Micro-Cracking, Cracking, and Reduced Durability of Concrete: Developing Methods for Quantifying the Influence of Cumulative Damage in Life-Cycle Modeling; 2004; Yang, Zhifu ; Weiss, W Jason; Olek, Jan; Joint Highway Transportation Program; Indiana DOT, Purdue University	Cracking, NDT, Detection, Measurement
While uncracked concrete exists as the best case scenario, frequent cracking occurs in real structures that could have a profound impact on life cycle performance. Cracks from several sources may accumulate and interact thereby accelerating the deterioration of concrete. For example, the distributed cracking caused by freeze/thaw damage can substantially increase the rate of water absorption and reduce the load carrying capacity of concrete. To accurately simulate the performance of actual concrete facilities, the role of cracking and its cumulative effect on the changes of material properties was intended to be accounted for in these models. The main goal of this investigation was to assess the influence of cumulative damage in concrete and to quantify its influence for use in life-cycle performance modeling. Samples were taken from five concrete pavement sections based on age, traffic, and overall performance to assess existing damage and to identify possible sources responsible for inducing the damage. These results were used as a baseline to assess the types of damage that merited laboratory investigation. After the field assessment, laboratory investigations were conducted to simulate the damage that may be expected in the field. After various levels of damage were introduced in laboratory specimens, durability tests (freezing and thawing and water absorption) and direct tensile tests were performed to develop an understanding of how the pre-existing damage accelerated the deterioration process. Specifically, it was determined that cracks caused by freezing and thawing dramatically increase the rate and amount of water absorption while cracks caused by mechanical loading only increased the absorption in a local region. Further, freeze-thaw damage dramatically reduces the direct tensile strength and modulus of elasticity of concrete until the aggregates begin to pull out of the matrix. This results in a larger fracture process zone in the damaged concrete than in the undamaged concrete.		
FHWA/TX-12/0-6348-2	Bridge Deck Reinforcement and PCP Cracking: Final Report; Oguzhan Bayrak, Shih-Ho Chao, James O. Jirsa, Richard E. Klingner, Umid Azimov, James Foreman, Stephen Foster, Netra Karki, Ki Yeon Kwon, and Aaron Woods; Center for Transportation Research, The University of Texas; TXDOT	Bridge Deck Cracking
Bridge decks composed of precast, pre-stressed panels (PCPs) overlain by cast-in-place (CIP) are popular in many states, including Texas. Optimization of top-mat reinforcement and reduction of collinear panel cracking were addressed in this project. Longitudinal top-mat reinforcement was found to be already optimized. Further optimization of transverse top-mat reinforcement is possible by slightly reducing the area of deformed reinforcement or by using welded-wire reinforcement. Collinear panel cracking can be reduced by reducing the initial pre-stress or by placing additional transverse reinforcement at panel ends. Measured pre-stress losses in PCPs were at most 25 ksi (kilo pounds per square inch), much less than the 45 ksi previously assumed by TxDOT. The comparative efficiency of different types of high-performance steel fibers was examined. Double-		

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<tr><td colspan="3">punch testing, appropriately standardized as proposed in this report, was found to be a reliable and repeatable measure of the comparative efficiency of high-performance steel fibers.</td></tr>
<tr><td colspan="3">3.4 BRIDGE INVENTORY
The Federal bridge inventory guide will be used together with the National Bridge Inventory System database to screen and select representative bridge types from the national inventory of bridges (using construction material and design bridge records). Additionally the code records will be used to extract statistical data with respect to total number of certain bridge types and the percentage of bridges that they represent. This information will be used for Posting Assessment and Cost Allocation sub-tasks.</td></tr>
<tr><td>FHWA-PD-96-001</td><td>Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges; 1995; Office of Engineering, Bridge Division</td><td>Bridge Inventory, NBIS</td></tr>
<tr><td colspan="3">This Guide has been prepared for use by the States, Federal and other agencies in recording and coding the data elements that will comprise the National Bridge Inventory data base. By having a complete and thorough inventory, an accurate report can be made to the Congress on the number and state of the Nation’s bridges. The Guide also provides the data necessary for the Federal Highway Administration (FHWA) and the Military Traffic Management Command to identify and classify the Strategic Highway Corridor Network and its connectors for defense purposes.</td></tr>
<tr><td colspan="3">3.5 DETERIORATION MODELS / Service Life</td></tr>
<tr><td>SHRP 2 PREPUB R19A</td><td>Design Guide for Bridges for Service Life; 2012; Principal Investigator: Atorod Azizinamini, Ph.D., P.E.; Florida International University, HDR Engineering, etc.</td><td>Deterioration Models, Bridge Design</td></tr>
<tr><td colspan="3">The main objective of the Guide is to provide information and define procedures to systematically design for service life and durability for both new and existing bridges. The objective of the Guide is to equip the user with knowledge that is needed to develop specific optimal solutions for a bridge under consideration in a systematic manner using a framework that is universal, but with specifics being different. The general frame work for design for service life is described, followed by addressing specifics related to each step by topics covered in various chapters.
In developing our bridge cost allocation method, we utilized a deterioration model based on our own experience and observations collected while inspecting thousands of bridges in the Northeast Region of the United States. The first step is understanding bridge behavior; the deterioration mechanism and the interaction of each element. Due to our intimate understanding of bridges through our bridge inspection and rehabilitation design background, the development of the deterioration model was rather intuitive. Based on review of this document, it is evident that a scientific approach is being proposed using the engineering community’s collective knowledge base.
The R19A document provides a scientific method to enhance the service life of bridges. It is a major shift in thinking for bridge design and preservation. New design methods are being proposed as a result of understanding how bridges deteriorate over time. It should be noted that this document is a work in progress and is being updated.</td></tr>
<tr><td>NCHRP SYN 234</td><td>Settlement of Bridge Approaches (The Bump at the End of the Bridge); 1997; Briaud, Ph.D., P.E, Jean-Louis; James, Ph.D., P.E., Ray W.; Hoffman, Stacey B.; Texas A&M University; http://www.ntis.gov/search/product.aspx?abbr=PB97179196</td><td>Bridge Design, Settlement, Deterioration Mechanisms</td></tr>
<tr><td colspan="3">This synthesis describes the current state of the practice for the design, construction, and maintenance of bridge approaches to reduce, eliminate, or compensate for settlement at the bridge/abutment/embankment interface or the bump at the end of the bridge. It discusses the geotechnical and structural engineering design and procedural factors, and includes numerous illustrations. This report of the Transportation Research Board presents data obtained from a review of the literature and a survey of the state DOTs. It is a supplemental update to Synthesis of Highway Practice 159: Design and Construction of Bridge Approaches (1990). The</td></tr>
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<tr><td colspan="3">synthesis identifies and describes techniques that have been used to alleviate the problem of the bump at the end of the bridge including the location and cause of settlement and methods used to reduce settlement. In addition, the types of interaction between various divisions of the DOTs in the design, construction, and maintenance of bridge approaches are addressed.
This synthesis was used as part of a comprehensive formulation of the Northeast Region deterioration model used (by CDM Smith in 2010) for the District of Columbia Truck Size and Weight Study. The premise of the deterioration model was the progressive failure mechanism initiated by failure of the bridge deck joints. One key reason for the deck joint failure is settlement of the approach slabs. In turn the settlements would cause impact onto the bridge deck joint itself causing the header beams to crack, armor plating to separate or seals to fail. In either case this was an initial entry point for water intrusion into and below the bridge deck which caused deterioration of the beams, bearing and bridge seats/pedestals.</td></tr>
<tr><td colspan="3">3.6 FATIGUE
As indicated in the Project Plan, the fatigue research is ongoing to identify relevant studies, projects and finite element models. Areas to be studied include load induced and distortion induced impacts on the fatigue life of steel bridges and concrete fatigue in bridge decks. Several articles related to the fatigue are included herein.</td></tr>
<tr><td>ASCE – Journal of Bridge Engineering</td><td>Truck Loading and Fatigue Damage Analysis for Girder Bridges Based on Weigh-in-Motion Data
http://ascelibrary.org/doi/pdf/10.1061/%28ASCE%291084-0702%282005%2910%3A1%2812%29</td><td>Fatigue</td></tr>
<tr><td colspan="3">Based on data collected by weigh-in-motion (WIM) measurements, truck traffic is synthesized by type and loading condition. Three-dimensional nonlinear models for the trucks with significant counts are developed from the measured data. Six simply supported multigirder steel bridges with spans ranging from 10.67 m (35 ft) to 42.67 m (140 ft) are analyzed using the proposed method. Road surface roughness is generated as transversely correlated random processes using the autoregressive and moving average model. The dynamic impact factor is taken as the average of 20 simulations of good road roughness. Live-load spectra are obtained by combining static responses with the calculated impact factors. A case study of the normal traffic from a specific site on interstate highway I-75 is illustrated. Static loading of the heaviest in each truck type is compared with that of the AASHTO standard design truck HS20-44. Several important trucks causing fatigue damage are found.</td></tr>
<tr><td>NSBA</td><td>A Fatigue Primer for Structural Engineers; 1998; Fisher, John W., Lehigh University; Kulak, Geoffrey L, University of Alberta; Smith, Ian F. C., Swiss Federal Institute of Technology; National Steel Bridge Alliance;
http://www.aisc.org/store/p-1638-a-fatigue-primer-for-structural-engineers-pdf-download.aspx</td><td>Fatigue, Fracture Critical, Design</td></tr>
<tr><td colspan="3">This publication from the National Steel Bridge Alliance provides guidelines for the understanding of fundamentals in the fatigue of metals, recognition of fracture critical details and provides tools to recognize and account for cracks in structures. The purpose of this publication is to provide a background of (information) to understand the design rules for fatigue strength that are currently part of the design codes for fabricated steel structures.</td></tr>
<tr><td>AISC -1977</td><td>Bridge Fatigue Guide Design & Detail; 1977; Fisher, John W., Lehigh University
http://www.aisc.org/search.aspx?id=3852&keyword=Bridge Fatigue Guide Design & Detail</td><td>Fatigue Guide</td></tr>
<tr><td colspan="3">This document is a guide and introduction to the fatigue problems in bridges, provides design details to optimize fatigue strength, concepts, considerations and examples for bridge engineers and designers.</td></tr>
</table>

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
NYSDOT TA 12-002	Fatigue Evaluation 100% Hand-on Exemption; https://www.dot.ny.gov/divisions/engineering/structures/repository/manuals/inspection/bim_ta12-002.pdf	Fatigue, Inspection
This document provides the means and methods for exempting the inspection of fatigue sensitive and fracture critical details by NYSDOT using various AASHTO publications. It is an indication of current practice by DOT's around the country.		
FHWA/IN/JTRP-2005/16-1	Fatigue of Older Bridges in Northern Indiana due to Overweight and Oversized Loads - Volume 1& 2: Bridge and Weigh-In-Motion Measurements; 2006; James A. Reisert and Mark D. Bowman; Purdue University; Indiana DOT; Joint Transportation Research Program http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1726&context=jtrp	Fatigue, Over-weight Truck Study, WIM
Abstract: This report is the first of a two-volume final report presenting the findings of the research work that was undertaken to evaluate the fatigue behavior of steel highway bridges on the extra heavy weight truck corridor in Northwest Indiana. The purpose of the study was to evaluate the type and magnitude of the loads that travel along the corridor and then assess the effect of those loads on the fatigue strength of the steel bridge structures. This volume presents the results of the experimental field study conducted to evaluate the load and load effects on one steel bridge structure on the corridor. A weigh-in-motion (WIM) system was installed near the bridge structure to evaluate the loads that would cross over the bridge being monitored. Strain values were monitored on two spans of the ten-span continuous bridge. Comparisons were then made between strain measurements in particular girders and strain values predicted using the measured truck axle weights. The WIM data indicated that 15% of the Class 9 trucks and 26% of the Class 13 trucks travel heavier than their respective legal limits. Extreme weights of more than 200,000 lbs were observed. In spite of the heavy truck loads being carried, it was found that less than 1 percent of the trucks induce a strain range that exceeds the variable amplitude fatigue limit of the fatigue critical details in the structure being monitored. Lastly, it was found that three dimensional analytical models provide the best agreement between predicted and measured strain values in the bridge. The titles of the two volumes (Report Number in parentheses) are listed below: Volume 1: Bridge and Weigh-In-Motion Measurements (FHWA/IN/JTRP-2005/16-1) Volume 2: Analysis Methods and Fatigue Evaluation (FHWA/IN/JTRP-2005/16-2)		
TRB Report 299	Fatigue Evaluation Procedures for Steel Bridges; F. Moses, C.G. Schilling, K.S. Raju, Case Western Reserve University http://www.trb.org/Publications/Pages/262.aspx	Fatigue
The primary purpose of this study was to develop improved procedures for the fatigue evaluation of existing steel bridges. A secondary objective was to develop improved procedures for the fatigue design of new steel bridges. The evaluation procedures are recommended for inclusion as Section 6 in the AASHTO Manual for Maintenance Inspection of Bridges and the design procedures are recommended for inclusion as Articles 10.3.1 and 10.3.2 in the AASHTO Standard Specifications for Highway Bridges.		
NSCC2009	Fatigue Prone Details in Steel Bridges; El Emrani, M; Kliger, R.; Chalmers University of Technology, Göteborg, Sweden http://www.nordicsteel2009.se/pdf/147.pdf	Fatigue
Abstract: This paper reviews the results of a large investigation of more than 100 fatigue damage cases, reported for steel and composite bridges. The damage cases were categorized according to the type of detail in which they were encountered and the mechanisms behind fatigue damage in each category were identified and studied. It was found that more than 90% of all reported damage cases are of the deformation-induced type and are generated by some kind of unintentional or otherwise overlooked interaction between different load-carrying members or systems in the bridge. Poor detailing, with unstiffened gaps and abrupt changes in stiffness at the connections between different members, also contributed to fatigue cracking in most details.		

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
Journal of Structural Engineering	Fatigue-Based Methodology for Managing Impact of Heavy-Permit Trucks on Steel Highway Bridges http://www.tucsa.org/images/yayinlar/makaleler/ASCE-SE-1995-high-cycle-fatigue-in-steel-bridges.pdf	Fatigue
Currently, in many areas of North America, special permits are issued to extra heavy vehicles without a detailed evaluation of individual components, considering only the ultimate capacity of the bridge inventory as a whole. Based on this, a large number of special permits have been issued to extra heavy vehicles. In this perspective, the ultimate and cumulative effect of such overloads on steel bridge components is studied. It is found that steel bridge members have adequate ultimate capacity to accommodate such overloads; however, they may suffer fatigue damage due to the cumulative effect of these overloads. Accordingly, a fatigue-based methodology is developed to assess the reduction in service life of bridges due to heavy–permit trucks. It is found that a reasonably large number of special permits can be issued at small reductions in fatigue life, but because stress ranges in excess of the constant-amplitude fatigue limit significantly alter the shape of the S-N curve, it is essential to appreciate that the concept of infinite fatigue life cannot be relied upon anymore.		
FL/DOT/RMC /6672-379	Influence of Heavy Trucks on Highway Bridges http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_STR/FDOT_BC379_rpt.pdf	Fatigue
The objective of this study includes the following aspects: (1) synthesize truck traffic data collected through WIM measurements; (2) establish live-load spectra; (3) perform fatigue damage analysis for typical bridges; (4) carry out static and dynamic analyses. Three-dimensional nonlinear mathematical models of typical trucks with significant counts are developed based on the measured axle weights and configurations. Road surface roughness is simulated as transversely correlated random processes. The multi-girder bridges are treated as a grillage beam system.		
LA State Project #: 736-99-1133	Monitoring System to Determine the Impact of Sugarcane Truckloads on Non-Interstate Bridges http://www.ltrc.lsu.edu/pdf/2009/fr_418.pdf	Fatigue
The study included in this report assessed the strength, serviceability, and economic impact caused by overweight trucks hauling sugar cane on Louisiana bridges. Researchers identified the highway routes and bridges being used to haul this commodity and statistically chose samples to use in the analysis. Approximately 84 bridges were involved in this study. Four different scenarios of load configuration were examined: 1. GVW = 100,000 lbs, with a maximum tandem load of 48,000 lb., 2. GVW = 100,000 lbs, with a maximum tridem load of 60,000 lb., 3. Uniformly distributed tandem and tridem loads, and 4. GVW = 120,000 lbs, with maximum tandem of 48,000 lbs, and maximum tridem of 60,000 lbs It is to be noted that a GVW of 120,000 lbs for sugarcane haulers was the highest level currently considered in this investigation. The methodology used to evaluate the fatigue cost of bridges was based on the following procedures: 1) determine the shear, moment, and deflection induced on each bridge type and span, and 2) develop a fatigue cost for each truck crossing with a) a maximum GVW of 120,000 lbs, and b) a GVW of 100,000 lbs with a uniformly distributed load. Through the use of a field calibrated finite element model, Structure 03234240405451 was analyzed and load rated for design loading vehicles including the HS-20 truck, a five axle truck (3S2) and a six-axle truck (3S3) that used four loading cases (Cases 1 through 4) and sugar cane as the commodity. The structure had adequate strength to resist both bending and shear forces for all six loading vehicles. It should be noted that all of the rating factors were acceptable for all 17 spans as long as the construction and the structural condition of each span were the same. Results indicate that among the four cases of loading configurations, Case 4, which was a GVW=120,000 lbs with maximum tandem and tridem loads, generated the worst strength and serviceability conditions in bridges. Therefore, Case 4 is the loading configuration that controls the strength analysis and evaluation of fatigue cost for bridge girders. Based on the		

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
controlling load configuration, Case 4 with a GVW = 120, 000 lbs, the estimated fatigue cost is $11.75 per trip per bridge. In Case 3, which was a GVW = 100,000 lbs uniformly distributed load; the estimated cost is $0.90 per trip per bridge. The results from the bridge deck analyses indicate that the bridge deck is under a stable stress state, whether the stresses are in the tension zone or the compression zone. Moreover, the decks of bridges with spans longer than 30 ft. may experience cracks in the longitudinal direction under 3S3 trucks. Such cracks will require additional inspections along with early and frequent maintenance. Based on the results of the studies presented in this report, it is recommended that truck configuration 3S3 be used to haul sugar cane with a GVW of 100,000 lbs uniformly distributed. This will result in the lowest fatigue cost on the network. It is recommended that truck configuration 3S3 not be used to haul sugar cane with GVW of 120,000 lbs This will result in high fatigue cost on the network and could cause failure in bridge girders and bridge decks.		
Journal of Civil Engineering and Architecture	Economic Impact of Higher Timber Truck Loads on Louisiana Bridges http://www.davidpublishing.com/davidpublishing/Upfile/5/21/2013/2013052171895729.pdf	Fatigue
Due to the limited amount of funds available for bridge inspection, maintenance and rehabilitation, the evaluation of load capacity for existing bridges is crucial to the Louisiana Department of Transportation and Development. This paper includes the development of a methodology to assess the economic impact of overweight vehicles with permits, hauling Louisiana harvest products on state bridges. The proposed higher truck loads are applied on the existing bridges and their effects are determined using deterministic load capacity evaluations as well as reliability assessments. The target reliability level is derived from bridge structures designed to satisfy AASHTO Standard Design Specifications and also satisfy safe and adequate performance levels. The amount of harvest produced is used to select a representative sample of bridges to provide specific examples of expected changes in load ratings and safety levels. The bridges include simple and continuous span behavior. Strength and serviceability criteria are investigated under current legal loads and the expected changes, due to the proposed new weights, are determined. The results are used to assess the cost of crossing a bridge and the permit fees for the proposed truck weight regulation.		
Journal of Bridge Engineering	Finite-Element Analysis of Steel Bridge Distortion-Induced Fatigue http://ascelibrary.org/doi/pdf/10.1061/%28ASCE%291084-0702%282003%298%3A5%28259%29	Fatigue
Welded plate girder bridges built before the mid-1980s are often susceptible to fatigue cracking driven by out-of-plane distortion. However, methods for prediction of secondary stresses are not specifically addressed by bridge design specifications. This paper presents a finite-element study of a two-girder bridge that developed web gap cracks at floor truss-girder connections. The modeling procedures performed in this research provide useful strategies that can be applied to determine the magnitude of distortion-induced stresses, to describe the behavior of crack development, and to assess the effectiveness of repair alternatives. The results indicate severe stress concentration at the crack initiation sites. The current repair method used at the positive moment region connections is found to be acceptable, but that used at the negative moment region connections is not satisfactory, and additional floor truss member removal is required. Stress ranges can be lowered below half of the constant amplitude fatigue threshold, and fatigue cracking is not expected to recur if the proposed retrofit approach is carried out.		
TRB 2003 Annual Meeting	Finite Element Study of Distortion-Induced Fatigue in Welded Steel Bridges http://www.ltrc.lsu.edu/TRB_82/TRB2003-001245.pdf	Fatigue
Out-of-plane distortion-induced fatigue cracking is caused by relative rotation and displacement between longitudinal girders and transverse members framing into these girders. Procedures for determination of		

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secondary stresses are not specified in the design or rating process. This paper presents appropriate finite element method procedures to analyze distortion-induced fatigue behavior. A multi-girder bridge developed web gap cracks near the girder bottom flange in a positive moment region. The affected diaphragm-girder connections were repaired by installing additional reinforcing splice plates to the web and attaching connection stiffeners to the flanges. Since no structural modifications were made to similar details in the bridge that had not developed fatigue cracks, concerns remain that these details may also be subjected to high magnitude fatigue stresses that may lead to future cracking. By using finite element sub-modeling techniques, potential crack initiation sites in the bridge were identified and the corresponding distortion-induced stresses were determined. The most stressed detail reached yielding with an out-of-plane displacement of only a few thousandths of an inch. Based on the analytical results, a linear stress displacement correlation was established for prediction of the secondary stresses. Repair analysis indicated that web gap stresses can be significantly reduced if a rigid stiffener-to-flange attachment is used. Thus, a bolted repair is recommended for the positive moment region connections and a welded repair is recommended for the transition and negative moment region connections.		
MN/RC-2003-16	Effects of Increasing Truck Weight on Steel and Pre-stressed Bridges http://www.dot.state.mn.us/ofrw/PDF/200316.pdf	
In summary this study found "any increase in legal truck weight would shorten the time for repair or replacement of many bridges. Five steel girder bridges and three pre-stressed concrete I-girder bridges were instrumented, load tested, and modeled. The results were used to assess the effects of a 10 or 20% increase in truck weight on bridges on a few key routes through the state. Essentially it was found that all pre-stressed girders, modern steel girders, and most bridge decks could tolerate a 20% increase in truck weight with no reduction in life. Unfortunately, most Minnesota steel girder bridges were designed before fatigue-design specifications were improved in the 1970s and 1980s. Typically, an increase in truck weight of 20% would lead to a reduction in the remaining life in these older steel bridges of up to 42% (a 10% increase would lead to a 25% reduction in fatigue life). **Bridge decks are affected by axle weights rather than overall truck weights.** Transverse cracks in bridge decks are primarily caused by shrinkage soon after construction and are not affected by increasing axle weight. However, decks with thickness less than 9 inches or with girder spacing greater than 10 ft may be susceptible to longitudinal flexural cracking which could decrease life." *This is an important finding for the current CTSW Study in general and as it relates to fatigue in bridge decks.*		
MN/RC – 2005-38	Analysis of Girder Differential Deflection and Web Gap Stress for Rapid Assessment of Distortional Fatigue in Multi-Girder Steel Bridges; MN/DOT http://www.lrrb.org/media/reports/200538.pdf	
Abstract: Distortion-induced fatigue cracking in unstiffened web gaps is common in steel bridges. Previous research by the Minnesota Department of Transportation (MN/DOT) developed methods to predict the peak web gap stress and maximum differential deflection based upon field data and finite element analyses from two skew supported steel bridges with staggered bent-plate and cross-brace diaphragms, respectively. This project aimed to test the applicability of the proposed methods to a varied spectrum of bridges in the MN/DOT inventory. An entire bridge model (macro-model) and a model encompassing a portion of the bridge surrounding the diaphragm (micro-model) were calibrated for two instrumented bridges. Dual-level analyses using the macro- and micro-models were performed to account for the uncertainties of boundary conditions. Parameter studies were conducted on the prototypical variations of the bridge models to define the sensitivity of diaphragm stress responses to typical diaphragm and bridge details. Based on these studies, the coefficient in the web gap stress formula was calibrated and a linear prediction of the coefficient was proposed for bridges with different span lengths. Additionally, the prediction of differential deflection was calibrated to include the influence of cross brace diaphragms, truck loading configurations and additional sidewalk railings. A simple approximation was also proposed for the influence of web gap lateral deflection on web gap stress.		

<table>
<tr><th>DOCUMENT No.</th><th>DOCUMENT TITLE & LINK</th><th>RELEVANCE TO STUDY</th></tr>
<tr><td>ENGINEERING JOURNAL
Volume 17
Issue 1</td><td>Finite Element Analysis of Distortion-Induced Web Gap Stresses in Multi-I Girder Steel Bridges

http://engj.org/index.php/ej/article/view/322/271</td><td></td></tr>
<tr><td colspan="3">Abstract: Unstiffened girder web gaps at the ends of transverse stiffeners that also serve as diaphragm connection plates are subjected to high local stresses during cyclic out-of-plane distortion. The out-of-plane distortion is mainly caused by the differential deflection between adjacent girders. The purpose of the paper is to investigate the effects of bridge parameters including span length, girder spacing, slab thickness, and girder stiffness on the differential deflection and distortion-induced web gap stresses. Dual-level finite element analyses that consist of both global model and sub-model were performed. The global model was used to investigate the critical truck position and maximum differential deflection between adjacent girders, while the sub-model was used for the critical web gap vertical stress. A base case bridge was a simply supported composite superstructure with three steel I-girders that support two traffic lanes, which is typical for steel bridges over intersections in Bangkok, Thailand. A parametric study was conducted by varying one bridge parameter at a time. The analysis results show that the maximum differential deflections and web gap stresses caused by one-truck loading are higher than those caused by two-truck loading (one truck on each lane). Under one-truck loading, the maximum web gap stress occurs at the interior girder. In addition, both the differential deflections and web gap stresses are primarily dependent on the bridge span length.</td></tr>
<tr><td>NCHRP SYN 354</td><td>Inspection and Management of Bridges with Fracture Critical Details; Conner, Robert, Purdue University; Dexter, Robert, University of Minnesota
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_354.pdf</td><td></td></tr>
<tr><td colspan="3">This report is focused on inspection and maintenance of bridges with fracture-critical members (FCMs). The AASHTO LRFD Bridge Design Specifications (LRFD Specifications) defines an FCM as a “component in tension whose failure is expected to result in the collapse of the bridge or the inability of the bridge to perform its function.” Note that the FCM can refer to a component such as a flange of a girder and does not necessarily include the whole “member.” Approximately 11% of the steel bridges in the United States have FCMs. Most of these (83%) are two-girder bridges and two-line trusses, and 43% of the FCMs are built-up riveted members.
The objectives of this synthesis project were to:
• Survey the extent of and identify gaps in the literature;
• Determine best practices and problems with how bridge owners define, identify, document, inspect, and manage bridges with fracture-critical details; and
• Identify research needs</td></tr>
<tr><td colspan="3">3.7 FREIGHT & MODAL SHIFT
These documents and articles are included for informational purposes, general background knowledge and or for specific tasks as the bridge cost allocation study proceeds. One of the critical pieces of information is having and understanding of freight modeling and how modal shifts occur. Although the forecasting and modeling is part of the CTSW Study Modal Shift team, it is important to understand how the process works, such that the modal shift can be accurately applied to the truck WIM spectra .Some of these articles may be included in the Modal Shift Desk Scan but are included here as well they relate to bridges.</td></tr>
<tr><td></td><td>Truck Loads and Highway Bridge Safety: New Developments; Gongkang Fu, Center for Advanced Bridge Engineering, Wayne State University; 2002</td><td>Cost Allocation, Modal Shift</td></tr>
<tr><td colspan="3">Abstract: This paper reports on some latest developments in efforts to balance truck loads and the capacity of highway bridges that carry the loads. One of them is the completion of the development of a method for estimating effects of truck weight limit change on bridge network costs, funded by the US National Cooperative Highway Research Program (NCHRP). Four categories of cost impact are addressed in this new</td></tr>
</table>

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
method: steel fatigue, reinforced concrete (RC) deck fatigue, inadequate existing bridges, and higher design load for new bridges. This development has taken into account the constraints on data availability at the State infrastructure system level. Another recent development is the completion of a research effort examining the adequacy of bridge design load for the State of Michigan in the US, with respect to real truck loads measured. It was found that there is a need to develop a more rational design load to cover the risk represented. These developments offer effective tools for response to the trend of increasing truck loads. *This article was quoted in the reference section of NCHRP Report 495. It is the main methodology used by Report 495 for utilizing the truck spectra (from WIM data) to predict truck load shift from one truck load fleet to another. As such it is a valuable document as we proceed with bridge cost allocation study.*		
SHRP2 S2-C20-RR-1	Freight Demand Modeling and Data Improvement; 2013; Chase, Keith M. Chase, Anater, Patrick; Gannett Fleming, Inc. Phelan, Thomas; Eng-Wong, Taub and Associates http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-C20-RR-1.pdf	Freight Demand; Modal Shift
• Determine freight demand modeling and data needs, in part by defining an optimal scenario or desired future state of what the freight planning process should be with all of the model parameters clearly identified and the necessary data available. • Identify and promote innovative research efforts to help develop new modeling and data collection and processing tools in the near and long-term future. • Establish and strengthen links between freight transportation planning tools and supporting data, and also consider the relationships between freight transportation and other areas of public interest, such as development and land use, in which freight movement has major implications. • Leverage and link existing practices, innovations, and technologies into a feasible approach for improved freight transportation planning and modeling. • Establish a recognized and regular venue to promote and support innovative ideas, modeling methods, data collection, and analysis tools as the basis for informing and sustaining further research.		
NCFRP RPT 22	Freight Data Cost Elements; Rensselaer Polytechnic Institute http://onlinepubs.trb.org/onlinepubs/ncfrp/ncfrp_rpt_022.pdf	Freight, Cost Allocation
NCFRP Project 26, "Freight Data Cost Elements," had the following objectives: • Identify the specific types of direct freight transportation cost data elements required for public investment, policy, and regulatory decision-making; and • Describe and assess different strategies for identifying and obtaining these cost data elements		
ASCE JBENF 2_13_6_556	Impact of Commercial Vehicle Weight Change on Highway Bridge Infrastructure; G. Fu; J. Feng; W. Dekelbab; F. Moses; H. Cohen; and D. Mertz; ASCE Journal of Bridge Engineering http://ascelibrary.org/doi/pdf/10.1061/%28ASCE%291084-0702%282008%2913%3A6%28556%29	Freight - Over Weight Truck Study
Truck weight limit is one of the major factors affecting bridge deterioration and expenditure for maintenance, repair, and/or replacement. Truck weight in this paper not only refers to the truck gross weight but also to the axle weights and spacings that affect load effects. This paper presents the concepts of a new methodology for estimating cost effects of truck weight limit changes on bridges in a transportation infrastructure network. The methodology can serve as a tool for studying impacts of such changes. The resulting knowledge is needed when examining new truck weight limits, several of which have been and are still being debated at both the state and federal levels in the United States. The development of this estimation method has considered maximizing the use of available data such as the bridge inventory at the state infrastructure system level. In application examples completed but not reported herein, the costs for relatively inadequate strength of existing bridges and for increased design requirement for new bridges were found dominant in the total impact cost.		
3.8 COST ALLOCATION STUDIES		

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY

The Cost Allocation section is divided into two subsections. First, Cost Allocation Studies are listed by states and then by country. Second, several cost allocation methods are provided.

3.8.1 CAS By State & Country

In this subsection cost allocation studies of 15 states are presented. Some states like Oregon conduct highway cost allocation studies (HCAS) biennially, however only the latest studies are shown herein. Indiana has conducted a 2013 HCAS; however their latest report is not available through the internet. There will be an ongoing effort to obtain that report (as well as others) as the methods and conclusions are of vital interest to this study.

The majority of the Federal HCAS reports conducted by each state follow the Federal HCAS method recommended in 2003with some modifications. The exception would be the Washington DC, District DOT Truck Size & Weight Study, 2010 conducted by CDM Smith will be used as a basis of this study. It should be noted that the Federal Cost Allocation Method for bridges has not been used on a nationwide basis and the data requirements presents considerable difficulties in expanding it to a national scale. The method was devised to provide uniformity for state and local agencies to conduct the studies on network of roads (toll road, trucking network) and could be expanded to the whole state if needed. California, Maryland and New York are states that have examined a limited network of roads. Most other states have studied a sampling of their bridges and extrapolated the results to the state-wide array of bridges.

The team has included the Australian HCAS study and the European Union CATRIN study as they provide alternate views, means and methods for such studies. A discussion of these studies is provided in the Bridge Task Project Plan. In brief, the Australians conducted a nationwide highway cost allocation study but used Passenger Car Equivalents (PCE) and Vehicle Kilometers Traveled (VKT) as the basis for the bridge cost share allocator. The European Cost Allocation Report (CATRIN) was a compilation of cost allocation studies conducted independently by 15 European Union countries on their roadway (and other transportation) networks. Our focus was on the bridge costs and the allocators used to proportion out cost responsibilities. What was apparent was that only a handful of countries like the Finland, Switzerland, and the Dutch tracked bridge costs separately. In each case the same allocator (Load related allocator –Equivalent Single Axle Load [ESALs] or ESAL kilometers) that was used on the pavements was also applied to the bridges. A few countries like Germany approached the allocation problem from a Top-Down or Econometric method as well as using Engineering type allocators like PCEs and VKTs.

What is clear from all of the foreign studies was the difficulty in obtaining data in a uniform format across political boundaries and what cost items (construction, rehabilitation, maintenance, etc.) to include or exclude from the studies. Although the US Federal method provides a uniform method for cost allocation, the states use the cost data in the format that they are used to collecting and there is no standardization.

Arizona

FHWA-AZ-06-528	Estimating the Cost of Overweight Vehicle Travel on Arizona Highways; Sandy H. Straus' ESRA Consulting Corporation http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ528.pdf	
FHWA-AZ99-477(1)	1999 Update of the Arizona Highway Cost Allocation Study; Arizona Department of Transportation; Carey, Jason; http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ477(1).pdf	
FHWA-AZ99-	Implementation of the Simplified Arizona Highway Cost Allocation	

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
477(3)	Study Model; Arizona Department of Transportation; Carey, Jason; http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ477(3).pdf	
Idaho		
023-2010 Idaho HCAS	2002 Idaho Highway Cost Allocation Study; SYDEC, Inc.; R.D. Mingo Associates; Harry Cohen Consultants; http://itd.idaho.gov/taskforce/resources/1040-Cost%20Allocation%202002.pdf	
017-2010 Idaho HCAS	2010 Idaho Highway Cost Allocation Study Final Report; Battelle; P Balducci; J Stowers; R Mingo; H Cohen; H Wolff; http://itd.idaho.gov/taskforce/2010%20Idaho%20HCAS%20Final%20Report_Oct%2024.pdf	
Indiana		
FHWA/IN/JHRP-89/4	1988 Update of the Indiana Highway Cost Allocation Study; Sinha, K.C.; Saha, S. K.; Fwa, T.F.; Tee, A.B.; Michael, H.L; Joint Transportation Research Program; http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2510&context=jtrp	
FHWA/IN/JHRP-84/20	Indiana Highway Cost Allocation Study: Final Report; Kumares C. Sinha; Tien Fang Fwa; Essam Abdel-Aziz Sharaf; Ah Beng Tee; Harold L. Michael; Joint Transportation Research Program; http://ia600401.us.archive.org/20/items/indianahighwayco00sinh/indianahighwayco00sinh.pdf	
Kentucky		
KTC-00-3	2000 Highway Cost Allocation Update; University of Kentucky, Kentucky Transportation Center; http://www.ktc.uky.edu/files/2012/06/KTC_00_03.pdf	
Maryland		
2009 MDTA HCAS	2009 Highway Cost Allocation Study for the Maryland Transportation Authority Toll Facilities; C. C. Fu; C. W. Schwartz; Erin Mahoney; University Of Maryland http://www.mdta.maryland.gov/Home/documents/Final_HCAS_FinalReport_052609.pdf	
Minnesota		
MN/RC 2012-14	2012 Highway Cost Allocation and Determination of Heavy Freight Truck Permit Fees; Gupta, Diwakar; University of Minnesota http://www.lrrb.org/media/reports/201214.pdf	
1990 MN HCAS	1990 Results of the Minnesota Highway User Cost Allocation Study; Cambridge Systematics, SYDEC, The Urban Institute, Jack Faucett Associates http://www.dot.state.mn.us/research/pdf/1990-00.pdf	
Nevada		
2009 NV HCAS	2009 Nevada Highway Cost Allocation Study; Battelle; P Balducci; J Stowers; R Mingo; H Cohen; H Wolff; http://www.nevadadot.com/uploadedFiles/2009_Cost_Allocation.pdf	
New Jersey		
FHWA-NJ-2001-030	Infrastructure Costs Attributable to Commercial Vehicles; Dr. Boilé, Maria; Ozbay, Kaan; Narayanan, Preethi , Rutger University,	

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
	Center for Advanced Infrastructure & Transportation http://cait.rutgers.edu/files/FHWA-NJ-2001-030.pdf	
New York		
	Effect of Overweight Vehicles on I-88 Bridges, Task 2.a &b Report – Draft for Part 1, March 2013; Graziano Fiorillo, Michel Ghosn; City College of New York	Cost Allocation
The object of this report is to describe a procedure that quantifies the effect to bridges caused by overweight trucks. The methodology is implemented on a representative sample of twenty three bridges along the I-88 corridor between Binghamton and Schenectady in New York State. The procedure is divided into three phases. In the first phase, the WIM data file which is assumed to be representative of the entire corridor is analyzed. In the second phase, the maximum moment response of each vehicle contained in the WIM file is obtained for each bridge by sending each truck through the appropriate influence line. Finally, each truck's response is used to estimate the effect caused by each truck. The cost analysis is executed for two types of effects: 1) Overstress effect and 2) fatigue effect. The overstress cost analysis follows the classical FHWA cost allocation model. The fatigue cost analysis follows the AASHTO LRFD fatigue analysis method. The cost model presented in this report is still preliminary pending the updating of the bridge design methodology that is taking place based on input from the Transportation Working Group (TWG). Furthermore, the unit cost data for the steel and concrete are based on the unit costs obtained from the RS Means Heavy Construction Costs Database. *As indicated above this bridge cost allocation study was conducted on 23 of the 40± bridges located on the I-88 corridor between Schoharie and Binghamton, NY. As indicated the Federal Incremental Method of cost allocation was used with some modifications.*		
Ohio		
2009 Ohio HCAS	Impacts of Permitted Trucking on Ohio's Transportation System and Economy; Director James G. Beasley, P.E., P.S. http://www.dot.state.oh.us/Divisions/Legislative/Documents/ImpactsofPermittedTrucking-Web.pdf	
Oregon		
2011 Oregon HCAS	2011 Oregon Highway Cost Allocation Study http://www.oregon.gov/DAS/OEA/docs/highwaycost/2003report to 2011report.pdf	
Tennessee		
2009 TN HCAS	Highway Cost Allocation for Tennessee Final Report; 2009; Garcia, Alberto; Huang, Baoshan; Dai, Yuanshun; Dong, Qiao; Celso, Jonathan. Document available upon request from TNDOT	
Texas		
0-1810-1	A Framework for the Texas Highway Cost Allocation Study; Luskin, David M.; Garcia-Diaz, Alberto; Lee, DongJu; Zhang, Zhanmin; Walton, C. Michael; University of Texas; Texas A&M University http://www.utexas.edu/research/ctr/pdf_reports/1810_1.pdf	
FHWA/TX-02-1810-2	Texas Highway Cost Allocation Study; Luskin, David M.; Garcia-Diaz, Alberto; Zhang, Zhanmin; Walton, C. Michael; University of Texas; Texas A&M University	

DOCUMENT No.	DOCUMENT TITLE & LINK	RELEVANCE TO STUDY
	http://www.utexas.edu/research/ctr/pdf_reports/1810_2.pdf	
Vermont		
1993 VT HCAS	1993 Vermont Highway Cost Allocation Study; SYDEC, Inc. http://www.ccrpcvt.org/library/freight/highway_cost_allocation_study_19930223.pdf	

Washington DC		
DDOT TSW 2010	District Wide Truck Size & Weight Study, Wilbur Smith Associates (CDM Smith & KS Engineers) 2010 *Available upon request from CDM Smith*	
Wisconsin		
WisDOT 0092-10-21 CFIRE 03-17	Aligning Oversize/Overweight (OSOW) Fees with Agency Costs: Critical Issues; Teresa Adams, Ph.D., Ernie Perry, Ph.D., Andrew Schwarts, Bob Gollnik, Myungook Kang, Jason Bittner and Steven Wagner; 2013	HCAS, OSOW Truck Study
This document attempts to address a number of issues regarding OSOW trucks in Wisconsin. Of relevance to the current CTSW Study is the attempt to allocate bridge cost to vehicles using the load based allocator – ESAL miles. This is one of the few states that have deviated from the Federal Cost Allocation method as outlined in this document.		
Australia		
	Third Heavy Vehicle Road Pricing Determination Technical Report, October 2005, Prepared by the National Transport Commission (NTC)	
The paper provided details of the NTC's calculation of heavy vehicles' share of road costs, used in preparing recommendations for a Third Heavy Vehicle Road Pricing Determination, to be implemented in 2006. *It should be noted that the Australian Bureau of Statistics is responsible for gathering both roadway cost data as well as vehicle usage data across states and territories and combining them in a uniform nationwide statistical database on an annual basis. This provides a common data bank with which to conduct cost allocation studies on a national basis.*		
Europe		
FP6-2005-TREN-4	Cost Allocation for Transportation Infrastructure (CATRIN) **- C**ost **A**llocation Practices in the European **Tr**ansport **In**frastructure Sector; 2008; European Transport Sector http://www.catrin-eu.org/index.php?option=com_docman&task=cat_view&gid=22&Itemid=29	
The CATRIN project aims to collect cost allocations from 15 European Union countries including the UK, Sweden, Germany, Switzerland, the Netherlands, the Dutch, Hungary, Poland, Greece, Turkey and more. The document does not aggregate the costs across the countries, but does provide several charts and tables summarizing the various methods.		
3.8.2 Cost Allocation Study Methods & Methodology		
NCHRP Synthesis 378	State Highway Cost Allocation Studies; A Synthesis of Highway Practice ; CONSULTANTS: Patrick Balducci, Battelle Memorial Institute, Joseph Stowers, Sydec, Inc.; 2008 http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_378.pdf	
This document provides a history of cost allocation studies and a compilation of methods used by various states. In that sense, it is similar to the EU CATRIN document.		

<table>
<tr><td></td><td>HCAS Bridge Analysis, (1997)
-Guidelines for Conducting a State Highway Cost Allocation Study Using the State HCAS Tool, 2000
-Documentation for Using the State HCAS Tool, 2000
Provided by the FHWA Office of Transportation Policy Studies (Mr. James March) and a team of consultants managed by Battelle Memorial Institute consisting of Roger Mingo, Joe Stowers, Harry Cohen, Holly Wolff, Dan Haling & Tom Foody.
http://www.fhwa.dot.gov/policy/hcas/final/index.htm</td><td></td></tr>
<tr><td colspan="3">The 1997 Federal HCAS Method outlines a uniform method to conduct state cost allocations. The bridge portion of the report attempts to standardize and refine the "incremental" method developed in 70s and 80s. The final report was published in 2000. The method provides a series interconnecting spreadsheets containing truck load spectra, WIM data, state cost data etc. to aid state conducting these studies.</td></tr>
<tr><td>NCHRP Report 495</td><td>Effect of Truck Weight on Bridge Network Costs; Gongkang Fu; Jihang Feng; Waseem Dekelbab; Center For Advanced Bridge Engineering, Wayne State University; Fred Moses; University Of Pittsburgh; Harry Cohen; Dennis Mertz; University Of Delaware; Paul Thompson (including the Software Module CARRIS 1.0, a series of interconnecting spreadsheet using WinBasic macros)
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_495.pdf</td><td></td></tr>
<tr><td colspan="3">NCHRP Report 495 has been the commonly used method in the US for state transportation agencies and jurisdictions to conduct cost allocation studies in a modified format for their entire network of bridges or for a specific trucking corridor. The method was a refinement of the Federal "Incremental" Highway Cost Allocation method of 1997. The full report provides appendices, look up tables, step by step procedures and examples for two states. In addition it includes a software CD for the CARRIS, excel based interconnecting spreadsheets. The method compiles costs based on four cost categories – Steel Fatigue Retrofits, Reinforced Concrete Deck Fatigue, and Deficiency due to existing bridge overstress and Deficiency due to new bridge overstress. The method investigates the load impact or effects of increasingly heavier trucks on the cost of posting, retrofitting or replacing a vulnerable bridge. It then extrapolates those costs to similar bridges on the network. The method is capable of investigating the effects of altering the mix of the trucks (modal shift) on the same cost categories listed above.
States have used this methodology in part or as whole to conduct bridge cost allocation studies. To our knowledge, a nationwide bridge study using this methodology has not occurred to date. As the name indicates, this is a "state" tool.
The fatigue methodology and formulations presented in this document will be included in one of the sub task studies on the fatigue related effects on reinforced concrete decks.</td></tr>
<tr><td>SWUTC/10/47 6660-00064-1</td><td>A Road Pricing Methodology for Infrastructure Cost Recovery; Southwest University Transportation Center; Conway, Alison J.; Walton, C. Michael ; 2010
http://d2dtl5nnlpfr0r.cloudfront.net/swutc.tamu.edu/publications/technicalreports/476660-00064-1.pdf</td><td>Highway Cost Allocation Method</td></tr>
<tr><td colspan="3">Abstract: The purpose of this research is to provide a theoretical framework for future commercial vehicle user-charging using real-time vehicle weight and configuration information collected using weigh-in-motion (WIM) systems. This work provides an extensive review of both mechanisms and technologies employed for commercial and passenger vehicle user-charging worldwide. Existing commercial vehicle-user charging structures use only broad vehicle classifications to distinguish between vehicles for the pricing of user-fees. The methodology proposed in this study employs highway cost allocation methods for development of an "Axle-Load" toll structure. A theoretical case study, based on information from Texas State Highway 130, is performed to explore the equity improvements that could be achieved through implementation of this proposed structure. Some sensitivity analysis is also performed to examine the potential revenue impacts due to</td></tr>
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<tr><td colspan="3">uncertainties in different data inputs under existing and proposed structures.</td></tr>
<tr><td></td><td>Cost Allocation By Uniform Traffic Removal Theoretical Discussion And Example Highway Cost Applications; 1992
Chris Hendrickson Department of Civil Engineering, Carnegie-Mellon University, and Kane, Anthony; Pergammon Press, UK
Office of Program and Policy Planning, Federal Highway Administration, Washington. DC 20590. U.S.A.
(Link not available)</td><td>HCAS</td></tr>
<tr><td colspan="3">Abstract: The paper proposes 4 methods for equitable roadway cost allocations: (a) allocated costs should be based on full cost recovery, (b) allocated costs must be non-negative for any traveler group, (c) cost allocations should be additive, and (d) cost allocations should be consistent where equivalency factors among traffic categories exist. For cases with well-behaved cost functions, the uniform traffic removal technique discussed here uniquely satisfies these four properties and should be used whenever the four allocation properties are desired. Example applications as well as cases in which cost functions are not well behaved are discussed</td></tr>
<tr><td>Paper 98-0417</td><td>Fatigue Impacts on Bridge Cost Allocation; Laman, J.A.; Ashbaugh, J.R., 1997
(Link not available)</td><td>HCAS, Fatigue</td></tr>
<tr><td colspan="3">The objective of this project was to develop an analytical tool to evaluate relative user responsibility for fatigue damage on highway bridges. The tool was a FORTRAN program designed to read standard format FHWA files on vehicle data including Vehicle Miles Traveled (VMT) and the output is a relative fatigue damage matrix for each weight group. The relative damage factors are then used in a cost allocation study to assign the cost of fatigue damage. 39 representative bridges throughout the United States were selected.
This was an interesting study in two ways. First it was a cost allocation method attempting to allocate cost not by a load based allocator but rather by a generic VMT allocator. This was a deviation from the Incremental Method. Secondly it is the only attempt at conducting a study on bridges on a national scale. There are potential weaknesses in terms of the allocators used and the number of bridges selected, however this may be due to computational power and technology available during the mid to late 90s.</td></tr>
<tr><td></td><td>Highway Cost Allocation Methodologies; Alemayehi Ambo, F.R. Wilson and A.M. Sevens; Transportation Group, University of New Brunswick, Fredericton, N.B. Canada; January 1991</td><td>HCAS</td></tr>
<tr><td colspan="3">Abstract: Four methodologies of life-cycle highway cost allocation were examined using the province of New Brunswick, Canada as a case study. The first two methodologies were reported by Wong and Markov. The third methodology was suggested by Rilett, et al. The fourth methodology was introduced as part of a research project. It was in line with the procedures practiced in public accounts for the construction and maintenance of roads on a continuing basis. The four methodologies were tested using the same data base pertaining to vehicle types; traffic measures (independent vehicle, passenger car equivalents, and equivalent standard axle loads); and costs of construction, maintenance, and rehabilitation. These data were applicable to a major two-lane highway in the study area. Six sites were selected for the case study. An analysis period of 60 years, three traffic growth scenarios, three pavement design periods were considered. Eleven types of vehicles comprising passenger cars, light trucks and vans, trucks, buses and recreational vehicles were used in the analysis. The assessment of the methodologies resulted in the recommendation of and suggestions for the costing of highways.
This was the only document related to Bridge Cost Allocation study in Canada. Studies referenced at the Transport Association of Canada web site refer to US studies. The team will continue to search for any relevant provincial or national Canadian Studies.</td></tr>
<tr><td colspan="3">3.9 TRUCK SIZE & WEIGHT STUDIES BY STATE
These articles/reports were collected to compile a list of vehicles from various states that were considered to carry loads in excess of the Federal Legal Limits and to understand the effects these vehicles have on bridges as reported by each state. Some of these articles also provide additional insight with regard to fatigue, state</td></tr>
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policies, posting and permitting. *Two articles, white papers one by Maine DOT and the other by Minnesota DOT were included based on our own research and by reference from the CTSW Study Web Site and will be indicated below.*		
Idaho		
	129,000 Pound Pilot Project: Report to the 62nd Idaho State Legislature. Idaho Transportation Department. January 2013. http://itd.idaho.gov/newsandinfo/Docs/129000%20Pound%20Pilot%20Project%20Report.pdf	Truck Size & Weight Study
This study quantifies damages based on NBI ratings before, during, and after the study for several different categories of bridges. This study does not consider the shift in modes of transport, or comment on the effects on other routes not included in the scope.		
Indiana		
FHWA/IN/JTRP-2007/10	Long-Term Effects of Super Heavy-Weight Vehicles on Bridges; http://docs.lib.purdue.edu/jtrp/236/	Permitted Truck Study
Abstract: A permit truck which exceeds the predefined limit of 108,000 lb. is defined as a superload in Indiana. This study was conducted to examine the long-term effects of superload trucks on the performance of typical slab-on-girder bridges and to assess the likelihood of causing immediate damage. Typical steel and pre-stressed concrete slab-on-girder type bridges were analyzed using both beam line analysis and detailed finite element models.		
FHWA/IN/JTRP-2010/12	A Synthesis of Overweight Truck Permitting; http://docs.lib.purdue.edu/jtrp/1118/	
For purposes of safety and system preservation, trucking operational characteristics are regulated through legislation and policies. However, special permits are granted for trucks to exceed specified operational restrictions. Thus, the Indiana DOT not only seeks highway operations policies that retain/attract heavy industry including those that haul large loads but also seeks to protect the billions of taxpayer dollars invested in highway infrastructure. As such, "it is sought to avoid policies that may lead to premature and accelerated deterioration of assets through excess loading or undue safety hazard through oversize loads. ..." Using data from a national study, the report quantifies the extent to which each additional payload increases pavement deterioration. The data also suggests that having more axles on a truck reduces pavement deterioration and consequently, damage repair cost, but could decrease the revenue to be derived from overweight permitting. In conclusion, the study recommended the conduction of a cost allocation study to update these load-damage relationships as well as the overweight permit fee structures, to reflect current conditions in Indiana.		
FHWA/IN/JTRP-2011/15	Evaluation of Effects of Super-Heavy Loading on the US-41 Bridge over the White River http://docs.lib.purdue.edu/jtrp/1491/	Super Loads, Fatigue
Built in 1958, the US-41 White River Bridge is a two-girder, riveted steel structure located in Hazelton, IN. The bridge is comprised of two, sixteen span superstructures sharing a common substructure. Each superstructure also contains four pin and hanger expansion joint assemblies. Long-term remote monitoring was used to quantify any negative effects due to the series of superloads. Five primary tasks were undertaken as part of this study: 1. Perform controlled load testing to gain insight on the typical behavior of the bridge. 2. Monitor the effect of individual superloads on the bridge structure to detect any notable damage. 3. Perform an in-depth fracture critical evaluation. 4. Evaluate the effects of multiple super-heavy loading events on the bridge. 5. Collect stress range histograms to be used as part of a fatigue life evaluation		
Louisiana		
LTRC_398	Effects of Hauling Timber, Lignite Coal and Coke Fuel on Louisiana Highways and Bridges, LTRC Report No. 398. Roberts, Freddy L.; Saber, Aziz; Ranadhir, Abhijeet; Zhou, Xiang. USDOT. March 2005.	Truck Study; Load Demands

	Available at http://www.ltrc.lsu.edu/pdf/2005/fr_398.pdf. Accessed: 5 June 2013	
This study provides a report on the performance of simple span as well as three span bridges of varying lengths. The performance is examined based on the ratios of maximum moment and shear of the exclusion vehicle compared to that of the bridge design vehicle. The sample bridges selected were designed with either H15 or HS20 truck loads. An in depth fatigue evaluation was not performed for this study. Instead the bridge life was determined using a simplified formula involving the performance ratio that was calculated. The added costs for these heavy trucks was then determined using the calculated bridge life.		
LTRC_228 TRB 09_228	Effects of Heavy Truck Operations on Repair Costs of Low-Volume Highways, LTRC Report No. 228. Saber, Aziz; Morvant, Mark J.; Zhang, Zhongjie. USDOT. 2009. Available at http://docs.trb.org/prp/09-0228.pdf	Truck Study; Fatigue
Abstract: The economic impact of overweight permitted vehicles hauling sugar cane on Louisiana highways is evaluated. The highway routes used to haul this commodity are identified and statistical samples are selected and analyzed. Two different vehicle types and three different gross vehicle weights are chosen including 100,000-lb and 120,000-lb AASHTO design guidelines are used to determine the effects of heavy loads on pavements and bridges. The approach requires the overlay thickness needed to carry traffic from each gross vehicle weight for the design period and costs based on 20-year period. State bridges are evaluated to satisfy regulations for the loading requirements and a fatigue cost is estimated for each safe crossing of a bridge.		
Maine		
	Engineering Analysis of Maine's Intestate Bridges, 100,000 Pound Six Axle Trucks, 2011 Sweeney, Kenneth L.; Getchell, Chip; http://www.maine.gov/mdot/docs/EngineeringAnalysis-of-MaineInterstateBridges8-15-11.pdf	Truck Size & Weight Study
In December 2009, the United States Congress authorized a one year Pilot Program that allowed Maine (and Vermont) to use State weight limits on the Interstate instead of the Federal cap of 80,000 lbs. Through two Executive Orders and then State legislation, Governor Baldacci and the Maine Legislature modified State law to allow a three-axle truck-tractor with a three-axle semi-trailer at 100,000 lbs to use Maine's entire Interstate system, effectively diverting large trucks from non-Interstate highways to the Interstate. Previously, this configuration was only authorized on the Maine Turnpike.		
	Interstate Highway Truck Weights – White Paper; Prepared by Maine DOT; September 20, 2010 http://www.maine.gov/mdot/truckweights/documents/pdf/MaineDOTTruckWeightPaper091020.pdf	CTSW Web Site, Truck Size & Weight Study, Safety
In Maine, 100,000-lbs six-axle semi-trailers have long been allowed to operate on approximately 22,500 miles of non-Interstate highways in the state. These same vehicles are unable to operate on approximately 250 miles of Maine's 367 miles of Interstate highways. This situation forces these semi-trailers to exit the controlled-access Interstate system and travel on secondary roads with numerous bridges, villages, intersections, driveways, schools, crosswalks and many other potential conflict points		
Executive Summary, Final Report , Appendices	Study of Impacts Caused by Exempting the Maine Turnpike and New Hampshire Turnpike from Federal Truck Weight Limits; June 2004; Wilbur Smith Associates; http://www.maine.gov/mdot/ofbs/documents/pdf/Non20Exempt20Final20Report.pdf	Truck Size & Weight Study
Abstract: Regulations governing truck size and weight have impacts on highway safety, infrastructure preservation and economic efficiency. In the United States (U.S.), federal laws govern truck size and weight (TS&W) on the Interstate Highway System. Federal TS&W laws are of particular importance to U.S. border-states heavily impacted by the North American Free Trade Agreement. Nearly all this trade travels by truck. Both Canada and Mexico allow significantly higher truck weight limits in their respective counties. As a result, U.S. companies competing against cross-border rivals in natural resource based industries, where profit		

margins are typically low find it difficult to compete against foreign competition that is able to use more efficient means of transportation.		
Position Paper	Impact and Analysis of Higher Vehicle Weight Limits on Minnesota Interstate System; March 2011; Minnesota DOT http://www.transportationproductivity.com/Studies/Minnesota_DOT.pdf	CTSW Web Site, Truck Size & Weight Study
Mn/DOT's Minnesota Truck Size and Weight Project (June, 2006) established Mn/DOT's position with regard to heavier trucks. The study views the topic from a standpoint of balancing infrastructure preservation, safety and economic benefits. Several neighboring states in the upper Midwest and Canada have higher vehicle weight limits than Minnesota. Many agricultural industries in Minnesota are impacted competitively by lower vehicle productivity in Minnesota. Current Truck Size and Weight limits (80,000 lb. on Interstate system) control the amount of payload that can be carried in a truck. An increase in vehicle weight limits would increase the allowable weight per trip, so fewer truck trips would be necessary to carry the same weight. Freight transportation cost savings due to increases in vehicle weight limits would benefit not only shippers and carriers but all consumers. There are two current bills in Congress (HR 763 and HR 801) that proposes increasing vehicle weight limits of vehicles using the national interstate system. These bills both display "opt-in" language, meaning that enabling State legislation is a requirement of the proposed law. *This paper was cited in the CTSW Study Web Site in light of the bridge study. Many bridges on the interstate system would potentially be impacted by this legislation*		
FR2	Minnesota Truck Size and Weight Project Final Report; 2006; Cambridge Systematics http://www.dot.state.mn.us/information/truckstudy/FR2_mndot_trucksizeweight_complete.pdf	Truck Size & Weight Study
This report summarizes the approach, findings, and recommendations of the Minnesota Truck Size and Weight (TS&W) Project led by the Minnesota Department of Transportation (Mn/DOT) in cooperation with other public and private stakeholders. The purpose of the project is to assess changes to Minnesota's TS&W laws that would benefit the Minnesota economy while protecting roadway infrastructure, bridges and safety.		
Texas		
FHWA/TX-10/0-6095-1; FHWA/TX-10/0-6095-2	Potential Use of Longer Combination Vehicles in Texas: First & Second Year Reports (multiple documents); ftp://ftp.dot.state.tx.us/pub/txdot-info/rti/psr/0-6095.pdf	Truck Study, LCV
Trucking remains the only major freight mode not to benefit from increases in size and weight regulations since 1982. The need for more productive trucks—both longer (LTL) and heavier (TL)—is growing with economic activity, rising fuel costs and concerns over environmental impacts from emissions. This study covers the first year activities of a two-year TxDOT-sponsored study into potential LCV use in Texas. It describes current U.S.LCV operations and regulations, operational characteristics of various LCV types, safety issues, and environmental and energy impacts, together with pavement and bridge consumption associated with LCVs. Methods to measure both pavement and bridge impacts on a route basis are described. A survey of current U.S. LCV operators provides an insight into business characteristics, vehicles, drivers, performance, and safety. The overall study benefited from three sources of direction: an advisory panel from TxDOT, an industry panel comprising heavy truck and LCV operators, and finally an academic team from the University of Michigan Transportation Research Institute. In the second year of the study, a series of routes and LCV types will be evaluated in Texas using methods developed in the first year and approved at a study workshop.		
Maine & Vermont – multiple studies		
me_vt_pilot; me_vt_congressrpt; vtpilot2012con	Maine and Vermont Interstate Highway Heavy Truck Pilot Program- 6-Month Report, Congressional Reports, Multiple Documents; Maine and Vermont Pilot Program Congress Report. The Report was prepared by a team of Federal & State Agencies (VDOT, MeDOT)	Truck Size & Weight for Maine & Vermont

grpt		
Section 194 of the Consolidated Appropriations Act, 2010 (Public Law (P.L.) 111-117), directs the Secretary of Transportation to study the impacts of the Maine and Vermont truck pilot programs, which replace Federal commercial-vehicle weight regulations with State limits on Interstate highways in those States. Public Law 111-117 also exempts Maine and Vermont from following Federal Bridge Formula B requirements mandated by Section 127 of Title 23, United States Code. **Abstract:** The purpose of this initial assessment is to report "...to the House and Senate Committee on Appropriations no later than six months after the start of the pilot program on the impact to date of the pilot program on bridge safety and weight impacts." Accordingly, this report presents the findings of the U.S. Department of Transportation (DOT) analysis which focuses on bridge safety and pavement performance. It discusses truck size and weight regulations in Maine and Vermont prior to and after passage of P.L. 111-117 and provides the most recent weigh-in-motion, registration, and permit data. The report also summarizes the findings of previous truck size and weight studies and highlights methodologies used to determine bridge load and operating ratings.		
West Virginia		
	An Analysis of Truck Size and Weight FOR WVDOT. Report will be available late summer 2013 as per Kent Sowards; (ksowards@njrati.org) Appalachian Transportation Institute, Marshall University, Huntington WV http://www.njirati.org	Truck Size & Weight Study; Cost Allocation
Abstract: A gap in the body of knowledge in the areas of cost allocation/infrastructure recovery and safety regarding increases in truck size and weight has been identified. The goal of this research is to critically evaluate the claims made by groups advocating for heavier and longer trucks and to update knowledge potential impacts to safety and infrastructure, including economic and fiscal consequences. Given that a Congressionally mandated study will be conducted over the next two years, the focus will be on completing this research effort to supplement the work that is being done by the Federal Highway Administration. The study will be divided into three main areas: safety, infrastructure, and cost recovery.		
Wisconsin		
	2009 Wisconsin Truck Size and Weight Study. Multiple documents. Wisconsin Traffic Operations and Safety Laboratory. Cambridge Systematics & Department of Civil and Environmental Engineering: University of Wisconsin-Madison. Available at http://www.topslab.wisc.edu/workgroups/wtsws.html	
This is a valuable study that considers the inclusion of six new heavy truck configurations. Study focuses on the inclusion of these configurations on both state highways as well as the combination of both state and federal highways. Study does look into several of the other areas that need to be addressed with heavier trucks including permitting and safety; however the evaluation of potential changes to shipping modes is lacking full attention. This is seen in the study's examination of rail-to-truck diversion. This portion of the study lack concrete data and partially relied on expert opinion.		
	Bloomberg- "Kraft Pushes for 97,000-Pound Trucks Called Bridge Wreckers" J. Plungis. Bloomberg.com, December 2011. http://www.bloomberg.com/news/2011-12-12/kraft-leads-push-for-97-000-pound-trucks.html	Truck Size and Weight Study
Emboldened by U.S. legislation allowing Maine and Vermont to keep 97,000-lb. trucks rumbling on their interstate highways, Kraft Foods Inc. and Home Depot Inc. are pressing more states to follow. Companies including Kraft—which says its trucks would drive 33 million fewer miles a year with higher weight limits nationwide—say they need to carry loads more efficiently to combat high diesel-fuel prices. Safety advocates say more heavy trucks would accelerate an increase in truck-related accident deaths, and question whether bridges can withstand the added weight. *This was another article cited by the CTSW Study Web Site regarding trucks with GVW over the Federal*		

Limits. It is included here for informational purposes and for understanding issues in general regarding overweight/oversize trucks as perceived by the public and as it relates to structural and cost impacts on bridges.

3.10 TRUCK TRAFFIC DATA		
Freight Facts and Figures 2012	Office of Freight Management and Operations- Freight Facts and Figures 2012; Office of Freight Management; http://www.freight.dot.gov	Freight
Freight Facts and Figures 2012 is a snapshot of the volume and value of freight flows in the United States, the physical network over which freight moves, the economic conditions that generate freight movements, the industry that carries freight, and the safety, energy, and environmental implications of freight transportation. This snapshot helps decision makers, planners, and the public understand the magnitude and importance of freight transportation to the economy. *This report provides information on freight volume and movement between modes of transportation. It is referenced by the team to better understand modal shift data and issues.*		
FHWA/IN/JT RP-2004/12	Quality Control Procedures for Weigh-in-Motion Data; Andrew P Nichols; *Marshall University*; Darcy M. Bullock, Purdue University; http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1647&context=jtrp	WIM Data
Abstract: For the past two decades, weigh-in-motion (WIM) sensors have been used in the United States to collect vehicle weight data for designing pavements and monitoring their performance. The use of these sensors is now being expanded for enforcement purposes to provide virtual weigh stations for screening vehicles in traffic streams for overweight violations. A study found that static weigh stations in Indiana were effective for identifying safety violations, but ineffective for identifying overweight vehicles. It was also determined that the alternative approach to identifying overweight vehicles using virtual weigh stations requires a high level of WIM data accuracy and reliability that can only be attained with a rigorous quality control program. Accurate WIM data is also essential to the success of the Long-term Pavement Performance project and the development of new pavement design methods. This report proposes a quality control program that addresses vehicle classification, speed, axle spacing, and weight accuracy by identifying robust metrics that can be continuously monitored using statistical process control procedures that differentiate between sensor noise and events that require intervention. The speed and axle spacing accuracy is assessed by examining the drive tandem axle spacing of the population of Class 9 vehicles. The weight accuracy is assessed by examining the left-right steer axle residual weight of the population of Class 9 vehicles. Data mining of these metrics revealed variations in the data caused by incorrect calibration, sensor failure, temperature, and precipitation. The accuracy metrics could be implemented in a performance-based specification for WIM systems that is more feasible to enforce than the current specifications based on comparing static vehicle weights with dynamic vehicle weights measured by the WIM sensors. The quality control program can also be used by agencies to prioritize maintenance to more effectively allocate the limited funds available for sensor repair and calibration. This research provides a tool that agencies can use to obtain and sustain higher quality WIM data. *This report provides detailed information on WIM sensors, how WIM data is collected, data mining and WIM data quality issues. It is essential in understanding the WIM data that will be provided by other task leads, quality and reliability issues.*		
NCHRP RPT 12-76	Protocols for Collecting and Using Traffic Data in Bridge Design; Bala Sivakumar, Michel Ghosn, Fred Moses; Lichtenstein Consulting Engineers, 2008 (Link not available)	WIM Data Scrubbing
This report documents and presents the results of a study to develop a set of protocols and methodologies for		

using available recent truck traffic data to develop and calibrate live load models for Load Resistance Factor Design (LRFD) bridge design. The HL-93, a combination of the HS20 truck and lane loads, was developed using 1975 truck data from the Ontario Ministry of Transportation to project a 75-year live-load occurrence. Because truck traffic volume and weight have increased and truck configurations have become more complex, the 1975 Ontario data do not represent present U.S traffic loadings. The goal of this project, therefore, was to develop a set of protocols and methodologies for using available recent truck traffic data collected at different US sites and recommend a step-by-step procedure that can be followed to obtain live load models for LRFD bridge design. The protocols are geared to address the collection, processing and use of national WIM data to develop and calibrate vehicular loads for LRFD superstructure design, fatigue design, deck design and design for overload permits. These protocols are appropriate for national use or data specific to a state or local jurisdiction where the truck weight regulations and/or traffic conditions may be significantly different from national standards. The study also gives practical examples of implementing these protocols with recent national WIM data drawn from states/sites around the country with different traffic exposures, load spectra, and truck configurations.		
NCHRP RPT 683	Protocols for Collecting and Using Traffic Data in Bridge Design. B. Sivakumar; M. Ghosn; F. Moses; TranSystems Corporation, 2011. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_683.pdf	WIM Data Scrubbing
This report provides a set of protocols and methodologies for using available recent truck traffic data to develop and calibrate vehicular loads for LRFD superstructure design, fatigue design, deck design, and design for overload permits. The protocols are geared to address the collection, processing, and use of national weigh-in-motion (WIM) data. The report also gives practical examples of implementing these protocols with recent national WIM data drawn from states/sites around the country with different traffic exposures, load spectra, and truck configurations. The material in this report will be of immediate interest to bridge engineers.		
The last two reports included in this section provide specific protocols for collecting WIM data used in this study, screening and scrubbing the data to achieve uniform conformity with accepted data collection standards. Data integrity issues arise in the process of collecting WIM data from multiple sites and/or multiple states to mesh them into a single WIM data collection for use in bridge studies. States collect WIM data in different manners and some have more enhanced procedures than others and provide inherently higher quality data.		

4.0 CONCLUSION

The reports, studies and articles presented above represent available information that is currently available from on-line university libraries, industry publications, State and Federal transportation agencies and other government and/or industry web sites. The collection provides a snapshot of ideas, methods, and research efforts from 1997 to 2013. Some of the latest documents of studies concluded in 2013 may not be available for review just yet, but we will make every effort to add them to this collection as this study progresses. As such this is a living document that is still evolving. All the articles and documents that are cited herein address the key issues to be investigated for the current CTSW Study as they relate to bridges.