APPENDIX B

Main Features of Selected Studies for Collecting and Using Traffic Data in Bridge Design

The technical literature search resulted in the compilation of a reference list consisting of approximately 250 abstracts, research papers, journal articles, conference papers, and reports with applicability to the project research. Of the examined material, approximately 70 applicable documents were selected for further evaluation and possible summary preparation. A tabulated summary (given below) of approximately 40 documents was prepared from the reviewed material. Contained in each document summary is a brief study description, the study findings (if any), and recommendations for further research suggested by the authors (if any).

Reference	Study Description	Findings	Recommendations
Lui, Cornell and Imbsen *Analysis of Bridge Truck Loads* (1998)	Presents statistical analysis of truck loading variables including gross vehicle weight (GVW) data collected at several weigh-in-motion (WIM) sites on roadways of various functional classifications in Florida and Wisconsin. Discusses the application of WIM data and truck loading statistical analysis to site-specific load model development for bridge evaluation.	The upper tail of Florida GVW probability distribution data collected during this study is similar to the results of previous studies. The upper tail of collected Wisconsin GVW probability distribution data reveals two abnormalities in the data collected at several WIM sites: 1). Vehicles weighing in excess of 100 Kips, more than the 80 Kips legal limit, 2). Overloaded trucks weighing between 120 and 150 Kips.	Two distinct aspects of the site-specific load model for bridge rating are important: 1). Realistic assessment of the load level, 2). Uncertainty reduction associated with loads. To manage an aging infrastructure with limited available resources, site-specific load model development for bridge evaluation must critically assess the uncertainties of the random variables that make up the model.
Moses, Ghosn and Snyder *Application of Load Spectra to Bridge Rating* (1984)	Presents methods of acquiring and applying live load spectrum data at a bridge site for evaluation purposes. A reliability based model is described that can calibrate appropriate load factors, predict maximum expected truck loading, and incorporate the measured statistics of girder distribution and impact.	AASHTO girder distribution factors are generally conservative compared to measured values from WIM data when trucks are occupying two lanes. Design specification moments used in evaluation have a greater uncertainty than a measured load spectrum determined at the site.	Reduced load factors for permit loads may be warranted for permit loads if the loading is carefully controlled. Load and resistance factors in rating calculations need to differ from factors applied to design because of exposure period and available performance data.

Reference	Study Description	Findings	Recommendations
Miao and Chan *Bridge Live Load Models from WIM Data* (2002)	Hong Kong based study presents a new methodology for deriving highway bridge live load models for short span bridges using WIM data. Two methods are presented to obtain extreme daily bending moments using WIM data: 1). The lane loading model is derived based upon the equivalent base length concept, 2). The truck loading model is developed based upon a statistical approach. The developed lane and truck loadings are compared with other loading models adopted locally and overseas.	The developed Hong Kong Bridge Design Load (HKBDL) (per lane) was found to be best represented by the following: 1). For a span of 0 to 5 m – a single axle load of 15.0 t, 2). For a span of 5 to 23.5 m – a single axle load of 8.0 t plus a uniformly distributed load, 3). For a span greater than or equal to 23.5 m – a uniformly distributed load over 23.5 m. After studying five possible truck models, the developed HKBDL (standard truck) was determined to be best represented by a six axle vehicle with a total length of 14.0 m. Axle loads vary from 7.5 t to 11.0 t and axle spacings vary from 1.3 m to 4.0 m. The proposed design loadings for Hong Kong, developed assuming a probability of 0.98 of the heaviest vehicle in Hong Kong, induce forces that are less than the design loading standards of many other countries.	Additional work is necessary to consider shear effects and effects on continuous spans. Load factors need to be studied for various combinations of loadings.
Heywood and Nowak *Bridge Live Load Models*(1989)	Australian study presents the analysis of WIM data. The data is statistically analyzed and normalized by the National Association of Australian State Road Authorities (NAASRA) T44 design loading, and the results of analysis are compared to current Load and Resistance Factor Design (LRFD) loading limit states.	The ratio of ultimate limit state (ULS) to serviceability limit state (SLS) moments based on statistically analyzed WIM data is approximately constant for each distribution considered, however it varies from 1.1 to 1.4 for all of the distributions studied. The ratio of the largest ULS (recurrence interval distribution) to the smallest SLS (normal distribution) moments	Develop a new bridge design live load in place of the T44 loading in order to provide a more uniform prediction of the effects of traffic loads on a variety of bridge spans. Consider revising the recurrence interval for the serviceability limit state so that this condition does not control the bridge design.

Reference	Study Description	Findings	Recommendations
		results in a value of 1.6. Similarly, the shear value varies from 1.4 to 1.5. Both the moment and shear values are less than the ultimate load factor of 2.0 that was proposed for the NAASRA Bridge Design Code.	
Nowak and Hong *Bridge Live-Load Models* (1991)	Presents a statistical procedure for calculation of live-load moments and shears for highway girder bridges of various span lengths with one and two lane configurations and using truck survey data collected by the Ontario Ministry of Transportation. The maximum load effects for time periods from one day to 75 years are produced from extrapolations and simulations.	The maximum moment and shear for single lane bridges up to approximately 100 feet long result form the application of a single truck. The study shows that two trucks following each other produce the maximum moment and shear for longer single lane bridges. The simulation results indicate that that two side-by-side perfectly correlated truck or lane loads, depending upon bridge length, is the governing two lane bridge live load model.	None.
Nowak and Szerszen *Bridge Load and Resistance Models* (1998)	As a part of the development of rational codes (the AASHTO LRFD Bridge Design Specifications, Ontario Highway Bridge Design Code, and Eurocode) for the design of bridges and evaluation of existing structures, presents a procedure for statistically calculating the live-load moments and shears for highway girder bridges using truck survey data collected by the Ontario Ministry of Transportation. Resulting bias factors for live load from the analysis are presented with the corresponding changes to the design live loads for the national	The maximum moment and shear for single lane bridges up to approximately 30 to 40 m feet long result form the application of a single truck. The study shows that two fully correlated trucks following each other produce the maximum moment and shear for longer single lane bridges. The simulation results indicate that that two side-by-side perfectly correlated truck or lane loads, depending upon bridge length, is the governing two lane bridge live load model for interior girders. One truck may govern in some cases for exterior girders.	None.

Reference	Study Description	Findings	Recommendations
	design codes.	The live load bias factors for moment and shear were found to be non-uniform for the span lengths investigated, necessitating a change in the live load model to produce a uniform factor. Current code girder distribution factors (GDF) were found to be inaccurate; long spans and large girder spacings result in conservative values, and short spans with small spacings result in non-conservative values.	
Moses *Calibration of Load Factors for Load and Resistance Factor Evaluation* (1999)	Outlines the derivations of the live load factors in the proposed AASHTO Condition Evaluation Manual using truck weight spectra. The use of site specific traffic data is addressed.	Live load factor calibration, using similar data from the LRFD code development, was necessary to allow greater flexibility for evaluation as compared to design (varying site traffic and permits, and amount of site traffic data retrieved).	None.
Nowak and Grouni *Calibration of the Ontario Highway Bridge Design Code 1991 Edition* (1994)	Describes the calculation of load and resistance factors for the Ontario Highway Bridge Design Code (OHBDC) 1991 edition, including the development of load and resistance models utilizing available truck surveys from Ontario, the selection of the reliability analysis method, and the calculation of reliability indices for bridge design and evaluation.	An analysis of the reliability indices for girder bridge types designed per the OHBDC (1983) revealed that they are generally lower than the desired target for shorter spans. Therefore, the existing design truck tandem axle load was increased from 140 kN to 160 kN. For the evaluation of existing bridges, the time dependent load model results in shears and moments that are 3% to 5% lower than those used for design and lower reliability indices are generally used as compared to design.	The following are the results of this study: 1). For design, the live load was modified and the tandem axle load was increased to 160 kN. 2). Modified load and resistance factors should be used for the evaluation of existing bridges depending upon the frequency of inspection, if the components have single or multiple paths, and if the components are primary or secondary members.
Nowak *Development of Bridge Load*	Using truck surveys, weigh-in-motion measurements, and other	The values of live load moments and shear from truck survey data (number	Based upon the results of the two lane model simulation, the girder

Reference	Study Description	Findings	Recommendations
Model for LRFD Code (1993)	observations, this paper describes the development of the LRFD load model for static live load.	of axles and axle spacing, and axle loads and gross vehicle weight) are determined by extrapolation for a wide range of simple and continuous spans. Both one and two lane conditions are considered for time periods of 1 day to 75 years. For the one lane condition, the maximum lane moment or shear is caused by one truck, or two or more trucks following each other, depending upon span length. For the two lane condition, distribution of truck load to the girders is very important. Simulations reveal that for interior girders, the case of two fully correlated side-by-side trucks governs.	distribution factors specified by AASHTO (1992) are generally too conservative, particularly for larger girder spacing. The proposed LRFD live load is recommended as the following: 1). The superposition of an HS20 vehicle and a uniform load of 640 lb/ft. 2). For shorter spans a tandem is specified. 3). For negative moments, use two HS20 vehicles, however reduce the total effect by 10 percent.
Agarwal and Cheung *Development of Loading-Truck Model and Live-Load Factor for the Canadian Standards Association CSA-S6 Code* (1987)	Presents the methodology utilized to develop the CS-*W* loading design truck and uniform live load factor for the Canadian Standards Association CSA-S6 code. Truck survey data was collected in seven Canadian provinces and used in the development of the design load model and live load factor.	Using survey data from Newfoundland, Ontario, and Alberta, the study found that for spans up to 20m, the proposed CS-600 design truck requires a higher load factor, reflecting a deficiency in the live load model for short spans. The design load was revised to ensure a uniform live load factor. Using survey data from Nova Scotia, Quebec, Saskatchewan, and British Columbia, the study found that each province demonstrated live load factors of similar magnitude.	For all types of live-load effects and ranges of span lengths a uniform live-load factor of 1.60 should be adopted. The CS-600 loading should be adopted as the standard bridge design load for Canadian interprovincial truck routes. A load level different from the CS-600 loading may be adopted by provincial and local authorities.
Nowak and Nassif *Live Load Models Based on WIM Data*	Michigan bridge WIM study compares measurements taken on three instrumented US route and Interstate	Weigh station data greatly underestimates the gross vehicle weights of overloaded truck traffic in Michigan. Truck weigh	None.

Reference	Study Description	Findings	Recommendations
(1992)	bridges to weigh station data.	station data is biased to less heavy vehicles due to trucker avoidance of the stationary scales. The study found that the gross weights collected at weigh stations were generally within the legal limits, however bridge WIM data shows that the structures are actually being significantly overloaded.	
Heywood *A Multiple Presence Load Model for Bridges* (1992)	Australian study investigates the use of WIM data to simulate multi-lane traffic crossing short span multiple lane bridges. Two lane bridges with spans less than 30 m long are simulated in this study, as this model is representative of the majority of Australian bridges.	The multiple presence simulation models indicate that for low traffic volumes the serviceability recurrence interval is significantly less than the proposed AASHTO value considering that the ultimate limit state is far less sensitive to changing traffic volume.	None.
Jaeger and Bakht *Multiple Presence Reduction Factors for Bridges* (1987)	Paper reviews the multiple presence reduction factors specified in the AASHTO and Ontario codes and provides an alternate method for establishing these factors for short and medium span bridges in relation to traffic volume using truck survey data. Factors for design and evaluation are proposed.	The multiple presence reduction factors by the proposed method using traffic density and truck weight distribution data are not significantly different from those of the AASHTO and Ontario codes.	Traffic density should be one of the deciding factors in choosing a multiple presence reduction factor value for design and evaluation. The reduction factors used in evaluation should also consider the expected remaining bridge life, the number of loaded lanes, and the time interval for vehicle to cross the middle third of the bridge, using the procedure presented in the paper.
Fu and Hag-Elsafi *New Safety-Based Checking Procedure for Overloads on Highway Bridges* (1996)	Using WIM data from United States sites and NYSDOT overload permit data, this paper presents an evaluation method for nondivisible overload permit checking using the LRFD concept of uniform bridge safety.	The paper proposes live load factors to be used in the checking procedure for annual and trip permits for overloaded trucks.	Incorporation of this bridge evaluation method for overweight trucks into code may be considered.
Fujino and Ito	Utilizing data from	The study shows that the	A revised design load is

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Probabilistic Analysis of Traffic Live Loading on Highway Bridges (1979)	surveys of traffic loads carried out on several Japanese highways, this paper summarizes the statistical analysis using computer simulation for the appraisal of the current design load and the development of a new design load.	current design load provides a safety reserve that is not constant for bridges of different span lengths, with a greater safety level provided for longer spans.	proposed, however the authors suggest analysis of continuous span bridges and further investigation of traffic flow on bridges.
Ghosn and Moses *Reliability Calibration of Bridge Design Code* (1986)	This study is the reliability calibration of the AASHTO bridge design code. The study incorporates two important concepts in bridge design load modeling: 1). The use of WIM to provide data on bridge loading and response for short and medium span bridges. 2). The use of reliability-based design to provide uniform reliability through a combined selection of nominal design loads and corresponding safety margins.	The reliability-based calibration of the AASHTO bridge design code revealed the following: 1). The AASHTO code provides high levels of reliability, but does not provide uniform reliability levels for all span lengths. 2). New safety factors and design loads are proposed to achieve uniform reliabilities or safety indices. 3). The target safety index was derived from average AASHTO performance. 4). The derived partial safety factors achieved more uniform safety indices. 5). Different live load factors are desirable for different loading intensities. 6). This approach to load modeling can be applied to bridge evaluation.	None.
Ghosn and Frangopol *Site-Specific Live Load Models for Bridge Evaluation* (1996)	Study focuses on the use of WIM to define site-specific bridge loads, and the differences in safety that result from applying site-specific values to evaluation rather than the national average (design loads).	For the bridge evaluation example presented, a safety index of 4.07 resulted from the use of the method presented in the Nowak (1993) model for design. Repeated with site-specific WIM data from two independent sites, the example resulted in safety indices of 3.69 and 3.03, displaying that the use of site-specific	The use of average live load data in the assessment of existing bridge reliability may not be representative of actual site conditions and actual site loading from WIM data should be utilized.

Reference	Study Description	Findings	Recommendations
		load data provides results that are different than those obtained from typical data.	
Laman and Nowak *Site-Specific Truck Loads on Bridges and Roads* (1997)	This study uses bridge WIM data to determine and compare site-specific bridge live loads at several locations on Interstate highways, state highways, US highways, and surface streets in Michigan. Weigh station data and truck citation data is utilized to verify the recorded truck loads by WIM.	The study shows that truck loads are strongly site specific and depends on factors such as traffic volume, local industry, and law enforcement effort. A negative correlation was found between law enforcement effort and the occurrence of overloaded trucks as overloaded trucks were found on roadways not controlled by truck weigh stations.	Additional truck data is needed to determine the site-specific load spectra for bridges. Rather than utilizing truck weigh station data, which is biased due to avoidance, unbiased WIM data is needed to determine accurate statistics for site-specific bridge live load models.
Nowak and Ferrand *Truck Load Models for Bridges* (2004)	Michigan bridge WIM study reviews some of the practical procedures used for field measurement of truck weights and uses this data to simulate site-specific truck loads.	The results of the WIM measurements show that truck traffic is strongly site specific and varies within a geographic area based on the number of trucks, gross vehicle weight, and axle weight. The study found that the shapes of the moment and shear distributions are almost identical, simplifying the bridge evaluation procedure since the same live load factors can be used for both moment and shear. Using the collected WIM data, maximum lane moments and shears were computed and compared to the AASHTO LRFD 1998 moments and shears. The maximum lane moments and shears due to the measured trucks vary between 0.6 and 2.0 times the AASHTO values.	None.
Frangopol, Goble and Tan *Truck Loading Data for a Probabilistic*	Study consists of a major bridge testing and analysis program for the FHWA. Thirty-five bridges in thirteen states	The study classified approximately 160,000 truck occurrences. Of these occurrences, approximately 6,881 fell	The data will be employed in the development of improved live load models for bridge design and

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Bridge Live Load Model (1992)	were tested using WIM.	into the multiple presence category, defined as a front axle-to-front axle spacing between vehicles of less than 120 feet. Side-by-side multiple presence was separated from same-line multiple presence. 5,516 side-by-side and 1,365 same-line multiple presence situations were recorded.	evaluation.
Fu and Hag-Elsafi *Vehicular Overloads: Load Model, Bridge Safety, and Permit Checking* (2000)	This study develops a live load model for truck traffic including overloads. The model is used to assess bridge safety subject to overloads and is designed to incorporate site-specific WIM data.	The paper proposes live load factors to be used in the checking procedure for annual and trip permits for overloaded trucks, consistent with the average bridge safety by the AASHTO code.	Consideration may be given to incorporating this bridge evaluation method for overloaded trucks into code.
Ghosn, Moses and Gabriel *Truck Data for Bridge Load Modeling* (1990)	Utilizing WIM data collected at several steel multi-girder Interstate bridges in Ohio, this study applies a simulation program that estimates the probabilistic distribution of maximum moment response of bridges. The study uses the model to develop a reliability-based truck weight formula that regulates the weight of trucks on US bridges. The developed truck weight formula is applicable to simply supported steel bridges designed for AASHTO's WSD HS20 loading and will have a .25 safety index for a 50 year life.	In the calculation of the truck weight formula, H, the random variable that gives the overload factor due to the presence of closely spaced vehicles, was found to be sensitive to only very large changes in truck volumes.	None.
Nyman *Calibration of Bridge Fatigue Design Model* (1985)	This study consists of a structural reliability evaluation of the current AASHTO fatigue specification for steel bridges using field data obtained from a bridge-mounted WIM system. A fatigue life failure model	The study has determined the following: 1). The proposed fatigue vehicle model is more representative of the current truck traffic at sites examined in the US. 2). The current AASHTO code appears to lead to	The proposed revisions to the current specification include: 1). Replacement of the current AASHTO fatigue design load model with Pavia's vehicle. 2). Modification of the allowable stress ranges to

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	is formulated in terms of a fatigue failure function.	safety indices that vary with the different stress categories. 3). Truck traffic including weight and volume vary too much from site to site to be covered by only two categories as currently done.	give a more uniform safety index for all stress categories. 3). Specification of different load factors for a range of volumes and loadometer values. 4). Refinement of the failure function variables to provide a more accurate safety index. The relationship between truck headway and volume also needs to be determined.
Caprani, Grave, O'Brien and O'Connor *Critical Loading Events for the Assessment of Medium Span Bridges* (2002)	Using WIM data from a French site, this study is the Monte-Carlo simulation of free-flowing traffic across bridges to determine the critical loading events and extreme load effects (bending moment and shear force).	The study shows that the two-truck event is the most important free-flowing event for short to medium span bridges with two opposing lanes of traffic. For longer spans, events involving three or more trucks can be significant.	Both two and three truck events should be modeled in the assessment of site-specific bridge loading for structure lengths up to 50 m and in free flowing situations.
Laman and Nowak *Fatigue-Load Models for Girder Bridges* (1996)	This paper focuses on the development of a new fatigue-load model for steel girder bridges using WIM data from five bridges. The data from the five structures consists of site-specific truck parameters and component-specific stress spectra.	The study findings indicate that the magnitude and frequency of truck loading are site-specific and component-specific. The results also reveal a significant variation in stress spectrum between girders. Generally, the girder that is located nearest to the left wheel track of vehicles traveling in the right lane experiences the highest stresses in the stress spectra and decreases as a function of the distance from this location. It was found that a vehicle that dominates the distribution of vehicle types does not necessarily dominate the fatigue damage of the particular component. Rather, a vehicle that dominates the distribution of the lane	A single truck model for fatigue loading is not recommended as the most accurate approach as a result of the site-specific nature of the distribution of vehicle types by axle. The paper recommends the use of an equivalent three axle fatigue truck with varying axle weight and spacings for sites with traffic consisting of two to nine axle trucks. Similarly, for sites with ten and eleven axle trucks, a four axle truck is recommended as an equivalent fatigue vehicle.

Reference	Study Description	Findings	Recommendations
		moments will likely dominate the fatigue analysis.	
Au, Lam, Agarwal and Tharmabala *Bridge Evaluation by Mean Load Method per the Canadian Highway Bridge Design Code* (2005)	This paper summarizes bridge evaluation by the Canadian Highway Bridge Design code (CHBDC) mean load method. The mean load method does not require the use of load or resistance factors. Instead, the uncertainties associated with the loads and resistances are considered by using default statistical parameters. The code also allows the use of parameters that are derived from collected site-specific WIM data. The paper compares the results of a steel box girder bridge evaluation using the mean load method default parameters, WIM derived parameters, and the LRFD method.	A comparison of the evaluation results shows that the LRFD method and the mean load method using the default statistical parameters provide similar results, with the mean load method offering a slightly higher live load capacity factor. The mean load method using live load statistics based on WIM data, provides the highest load carrying capacity. This is a result of the conservative statistical parameters provided in the CHBDC.	Mean load method evaluation results using WIM data may not be conclusive if the bridge's most critical traffic loading periods are missed during field data collection. The season and measurement periods require thoughtful selection to capture the most critical live loading on the bridge.
van de Lindt, Fu, Zhou and Pablo *Locality of Truck Loads and Adequacy of Bridge Design Load* (2005)	This paper investigates the differences in live loading conditions between the national average as utilized in the AASHTO LRFD code and twenty site-specific Detroit, Michigan girder bridge locations. Resulting reliability indices are compared. WIM data is used to characterize the truck load effect in the bridges' primary members for moment and shear at critical cross sections.	This study established the following: 1). In general, the local truck loading may vary significantly from the state or national average, resulting in inconsistent risk levels for highway bridges. 2). Based upon the study findings of the twenty subject bridges, the current Michigan HS25 design load does not consistently achieve a reliability index of 3.5 for the design-minimum strength of bridges in the Detroit area.	This WIM data used in this study did not include headroom information. Further study incorporating WIM data with headroom information should be performed to advance the study topic. Site-specific live load analyses are necessary, particularly for trunkline roadways with high ADTTs, in order to achieve a more uniform reliability index. Consideration should be given to performing a feasibility study at the national level.
Cohen, Fu, Dekelbab and Moses	Using WIM and truck survey data, this study presents a qualitative	This study has established the following: 1). The modeling is based	None.

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Predicting Truck Load Spectra Under Weight Limit Changes and its Application to Steel Bridge Fatigue Assessment (2003)	method of predicting truck load spectra as a result of changing truck weight limits. This study utilizes historical and present truck weight data and can be used to estimate the impact of weight changes on bridges.	on freight transportation behavior, and it is flexible for both national and local changes. 2). Using measured truck data from Arkansas and Idaho, the paper shows that the proposed method can capture effects of truck weight-limit change on TWHs and on resulting steel bridge fatigue. 3). This method can be used to estimate possible impacts to bridges as a result of truck weight-limit changes, in developing rational policies for freight transportation.	
Moses *Probabilistic Load Modeling for Bridge Fatigue Studies* (1982)	The author presents a reliability model to provide consistent levels of fatigue safety for steel girder bridges. Discussions of shortcomings with truck data collection systems are offered.	Since the fatigue model is considerably influenced by the heavy end of the weight spectra, a WIM system was developed as part of this study to collect truck data. It was found that weigh stations and temporary weigh scales are avoided by overloaded trucks, resulting in biased data. The study found that pavement weigh scales provide erroneous static truck weights due to adjacent pavement roughness and that their proposed bridge WIM system offers more accurate data.	The paper recommends that following for future consideration: 1). The allowable stress range for fatigue should be made a continuous function of truck volume instead of discrete volume categories. 2). The nominal loading should coincide with a representative vehicle with expected dimensions and axle load percentages instead of a variable wheelbase vehicle. 3). Safety indices for non-redundant structures should be based on risk models that integrate load probability occurrences over a range of damage. Models should be developed to produce consistent safety for redundant and non-redundant behavior. 4). Future tests should involve multi-lane measurements to monitor vehicle combinations.
Wang, Liu, Hwang and	Using data from a Florida WIM station, this study	This study has found the following:	None.

Reference	Study Description	Findings	Recommendations
Shahawy *Truck Loading and Fatigue Damage Analysis for Girder Bridges Based on Weigh-in-Motion Data* (2005)	synthesizes the truck traffic data and establishes the live-load spectra, and performs a fatigue damage analysis for six typical steel multi-girder bridge models that were generated for this project.	1). Flexural stress and shear vary with bridge span length. 2). Truck loading on the bridges does not necessarily increase with GVW, but rather with axle weight. Tandem axles significantly exceed the loading of an HS20-44 vehicle. 3). The average impact factors are generally less than the values specified in AASHTO (1996). 4). The AASHTO fatigue truck and the actual truck-traffic flow based on with measurements have close effects.	
Grundy and Boully *Fatigue Design in the New Australian Bridge Design Code* (2004)	This paper presents an overview of the work performed in developing the fatigue provisions for the new Australian Bridge Design Code AS5100. Calibration of the fatigue loading model against Culway WIM data is described. The projected growth in traffic volume and magnitude of vehicle and axle mass is incorporated in the fatigue loading model.	The following was noted: 1). Span has a great effect on the fatigue damage per truck. For short steel bridges, fatigue can become the governing limit state for structures on heavily traveled roadways. For longer spans, fatigue is not as great an issue due to the effect of dead load. 2). Multiple presence of trucks in the same or adjacent lanes occurs infrequently per the WIM data.	None.
Jamera et al *FHWA Study Tour for European Traffic-Monitoring Programs and Technologies* (1997)	This FHWA-sponsored study is a scanning tour of the Netherlands, Switzerland, Germany, France, and the United Kingdom. The tour was conducted in order to learn how European countries perform traffic monitoring and if and how these concepts can be applied in the United States. Several areas of specific interest regarding WIM system and data collection were reviewed	The study found the following: 1). Fewer and less detailed data are collected on trucks than in the US. 2). Standardization of data collection equipment is common. The Europeans are working to coordinate WIM research and development to produce better, more reliable WIM equipment (DIVINE, COST 323, and WAVE projects). 3). WIM systems require	The study recommends that there are two areas in which US transportation experts should pay attention to European WIM systems and activities: 1). The Europeans employ limited classification schemes, allowing the use of less sophisticated and less costly collection equipment. An analysis of cost savings versus loss of detailed

Reference	Study Description	Findings	Recommendations
	and summarized.	calibration at least twice a year. 4). Only France and the United Kingdom have extensive WIM system installations.	information requires analysis. 2). The COST and WAVE WIM tests should be monitored by US researchers to eliminate duplicate efforts in this county.
O'Brien and Caprani *Headway Modelling for Traffic Load Assessment of Short to Medium Span Bridges* (2005)	The assumed headways of successive trucks on bridges have a great impact on the critical loading events from which the characteristic effects are derived. This paper presents a new approach that uses measured headway statistical distributions generated from French WIM data.	The following has been established from this study: 1). Headways of less than 1.5 sec. were found to be insensitive to traffic flow and are influenced by driver behavior. Headways between 1.5 sec. And 4.0 sec. were found to be considerably influenced by traffic flow. 2). Assumptions related to headways and gaps have a great impact on load effects and characteristic values.	The authors recommend a statistical (HeDS) approach for site-specific assessment of bridge loading.
van de Lindt, Fu, Pablo and Zhou *Investigation of the Adequacy of Current Design Loads in the State of Michigan* (2002)	This report presents the process and results of a research effort to examine the adequacy of current vehicle loads used to design bridges in the State of Michigan. The target reliability index used in the AASHTO LRFD code was utilized in the study as the criterion for evaluating the adequacy. Reliability indices were calculated for twenty different bridges selected from the Michigan inventory of new bridges. Existing WIM data was processed to statistically characterize the truck load effect.	The following conclusions were made by the report: 1). The reliability indices were found to vary among bridge types. 2). The 50^{th} and 90^{th} percentile of traffic volume do not noticeably influence the reliability indices. 3). The current design load, HS25, could be modified to achieve, on average, a reliability index of 3.5, which was used as a target index for the AASHTO LRFD code. 4). The deck design load of HS20 is adequate for reinforced concrete decks.	The authors recommend that a new design load level be considered for bridge beam design in the Detroit Metro Region.
Nichols and Bullock *Quality Control Procedures for Weigh-in-Motion Data*	This study consists of the development of a quality control program for the Indiana Department of Transportation to improve the accuracy of	The study found the following: 1). The WIM applications at static weigh stations were effective for identifying safety	The study recommended the following: 1). The drive tandem axle spacing metric should be applied to all WIM systems to monitor the

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(2004)	the data produced from their WIM sites. The quality control program is based on the Six Sigma quality control program DMAIC performance improvement model and provides a mechanism for assessing the accuracy of vehicle classification, weight, speed, and axle spacing data and monitoring it over time.	violations, but ineffective for identifying overweight vehicles. Virtual weigh stations in Indiana were found to be approximately 55 times more effective than the static weigh stations for overweight truck identification. 2). Robust metrics for speed and axle spacing accuracy, weight accuracy, and sensor error rates are necessary in a quality control program that can be continuously monitored using statistical process control procedures. 3). Data mining of these metrics revealed variations in the data caused by incorrect calibration, sensor failure, temperature, and precipitation.	speed calibration and prioritize maintenance on a lane basis. 2). The bending plate and single load cell WIM systems should be configured to log the left and right wheel data to compute the left-right residual metric. Use the left-right residual for detecting weight calibration drift and to prioritize maintenance on a lane basis. 3). The error proportion metric should be applied to all WIM systems to identify lanes that experience high error rates to prioritize maintenance on a lane basis. 4). The WIM data should be continuously monitored for errors and drifts to establish and maintain accurate data. 5). The WIM system algorithms should consider variations in the climate to account for temperature and precipitation or flag data that is collected during days of climatic anomalies when the accuracy is questionable. 6). To apply the recommended quality control procedures, the WIM data must be uploaded to a relational database that supports free-form queries. Analysis cubes are recommended for data mining. 7). A test bed should be constructed of various types of WIM sensor for long-term evaluation of performance, accuracy, and maintenance costs for

Reference	Study Description	Findings	Recommendations
			each type. Installation of equipment to collect continuous climate data would allow further exploration of the climatic impacts on the WIM sensors.
Hwang and Koh *Simulation of Bridge Live Load Effects* (2000)	The current design load in Korea, which is not based on any research or actual data, was adopted in 1978. This paper presents the research for the new live load model for the reliability-based design code that is based on collected bridge WIM data and video recording. The new model is compared to the design live load model from several countries.	The study has determined the following: 1). The new live load model should consist of a combination of truck load and distributed load with a varying magnitude based on span length. 2). Weight distributions differ for each WIM site and direction, highlighting the importance of accurate data for the live load model. 3). The maximum moment ratio is variable based on span length. A single truck controls for shorter span lengths and two fully correlated trucks govern for longer spans.	The paper suggests that additional data should be collected to better represent truck load effects.
O'Connor and O'Brien *Traffic Load Modelling and Factors Influencing the Accuracy of Predicted Extremes* (2005)	This paper describes traffic simulation (direct and Monte Carlo method) using European WIM statistics for the assessment of existing bridges. The implications of the accuracy of the recorded data and the duration of recording and of the sensitivity of the extreme to the method of prediction are investigated. Traffic evolution with time is also explored.	The paper offers the following findings: 1). The accuracy of the extreme load effects by Monte Carlo simulation increases with increasing span length in inverse proportion to the variance in the extreme. 2). A comparison of extrapolation techniques shows the importance of appropriate selection of an extreme value distribution. 3). The accuracy of WIM data is more critical for shorter span lengths. The effects of increasing inaccuracy were seen to attenuate with span. 4). The time-dependent and seasonal analyses do not provide any clear	None.

Reference	Study Description	Findings	Recommendations
		proof of a seasonal trend. 5). When considering future growth, it is found that the factor that could have major influence on predicted extremes in the future is a change allowable gross vehicle weight. 6). The sensitivity of characteristic extremes to the duration of recording and the amount of available data is a function of the effect and span under consideration.	
Lu, Harvey, Le, Lea, Quinley, Redo and Avis *Truck Traffic Analysis Using Weigh-In-Motion (WIM) Data in California* (2002)	This report is based on truck traffic data collected from all of the WIM stations on the California State highway network. Two objectives of the study were to determine truck traffic volume and load growth trends using regression methods and to check the possibility of extrapolating available truck traffic data to sites where WIM stations are not installed.	The report concluded the following: 1). Axle load spectra are heavier at night than during the daytime, possibly due to more efficient operation without car traffic or avoidance due to closure of more weigh stations. 2). Axle load spectra shows little seasonal variation. 3). Axle load spectra are much higher at rural WIM stations compared to urban stations, likely due to the presence of more long-haul trucking at rural WIM stations, and more short-haul, less-than-full-load trucking in urban areas. 4). The proportion of larger truck types, which would more typically be used for long-haul trucking, increases at night. 5). The analysis of six representative WIM sites shows that GVW generally did not grow across the six sites. Although the number of trucks using the highways increased, the trucks were	The following recommendations were made: 1). Further research should be conducted to improve methods of estimation for locations that are not equipped with WIM systems. 2) Several recommendations were made regarding improvement to the capability of the WIM data collection system including regular quality assurance checks and maintenance at all WIM stations.

Reference	Study Description	Findings	Recommendations
		generally not carrying heavier loads. 6). Axle load spectra can generally be extrapolated for steering and single axles to adjacent sites.	
O'Brien and Znidaric *Report of Work Package 1.2 – Bridge WIM Systems (B-WIM)* (2001)	This work package 1.2 report is part of the Weigh-in-motion of Road Vehicles for Europe (WAVE) study and focuses on bridge WIM systems. The objectives of the study are to understand the dynamics of a truck crossing event, to develop a bridge WIM system, to develop new approaches and algorithms, to investigate the possibility of systems that are free of axle detectors, and to test the accuracy of bridge WIM systems.	The study has shown that major difficulties observed with bridge WIM systems in the past can be avoided when using new and updated algorithms and more powerful computers and data-acquisition systems. The study results indicate that bridge WIM systems have an accuracy comparable to other types of WIM systems. Several advantages of the bridge WIM system include portability, durability, and the lack of influence of the pavement on the weighing accuracy. One issue that has not been addressed by this study is the multiple presence of more than one heavy vehicle on the bridge at the time of weighing.	The further development of free of axle detector systems is necessary as there are many potential improvements in accuracy and in the range of bridge types to which it can be applied.
Chotickai and Bowman *Truck Models for Improved Fatigue Life Predictions of Steel Bridges* (2006)	This paper presents the development of a new fatigue model based on WIM data collected from three different sites in Indiana. The recorded truck traffic was simulated over analytical bridge models to investigate moment range responses of bridge structures under truck traffic loadings. The bridge models include simple and two equally continuous spans. Based on Miner's hypothesis, fatigue damage accumulations were computed for details at	Based on the analysis of the WIM database, the paper shows that the effective fatigue stress range is site-specific and can be significantly different from the gross weight specified for the AASHTO fatigue truck. The simulation results indicate that the use of the studied fatigue trucks in a fatigue evaluation of bridge structures subjected to different truck traffic loadings can result in a considerable underestimation or overestimation of the extent of the actual	The paper recommends the use of the newly developed fatigue trucks. The three-axle fatigue truck can be used to represent truck traffic on typical highways with a majority of the fatigue damage dominated by two- to five-axle trucks. The new four-axle truck can better estimate the fatigue damage on heavy duty highways with more than 10% of the truck traffic dominated by eight- to eleven-axle trucks.

Reference	Study Description	Findings	Recommendations
	various locations on the bridge models and compared with the damage predicted for the AASHTO fatigue truck, a modified AASHTO fatigue truck with an equivalent gross weight, and other fatigue truck models.	fatigue damage when compared to the damage predicted using the WIM database.	
Tallin and Petreshock *Modeling Fatigue Loads for Steel Bridges* (1990)	Using WIM data from seven states, histograms of truck GVW are analyzed. These histograms are modeled by two bimodal distributions. Fatigue lifetimes for AASHTO categories A, B, C, and E details are calculated from these distribution of GVW models by approximating the Miner's stress as a linear function of the *m*th root of the *m*th expected moment of the GVW. The lifetimes based on the two models are compared with each other and with the results obtained by assuming a single lognormal distribution.	The study results show that the fatigue lifetimes for AASHTO categories A, B, C, and E details estimated using the bimodal distributions differ little from each other but are significantly shorter than the lifetimes estimated from the single lognormal distribution. It was also noted that there are large differences between the estimated lifetimes of different AASHTO fatigue categories.	None.