Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Developing Notification and Enforcement Systems to Communicate and Administer Bridge Load Postings

Project No. 20ITSLSU17

Lead University: Louisiana State University

Final Report

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Disclaimer

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16. Abstract

State and local law enforcement agencies in the US strive to enforce weight restrictions on trucks and heavy vehicles travelling on public roads as a matter of public safety and as a way of safeguarding vital transportation infrastructure.

This research aimed to identify plausible notification systems that can effectively communicate bridge load postings to dispatchers and drivers, investigate and suggest possible approaches to communicate potential detour routes, and identify corresponding enforcement methods required to successfully administer bridge load postings.

This report discusses the current practices of bridge load posting notification and enforcement systems. Also, it presents an overview of the existing conditions of intelligent Transportation systems (ITS) in Louisiana that included: Traffic Management Centers (TMCs), Motorist Assistance Patrol (MAP) service, ITS devices, and technologies. A national survey was also conduct targeting US Departments of Transportation (DOTs) professionals and law enforcement agencies in USA to obtain their feedback and insights regarding the current bridge load posting notification and enforcement procedures/systems, its limitations and required modifications at their States.

The results of this research suggest that improving the notification methods alone is not enough to ensure public compliance with posted weight limit on bridges, therefore, the enforcement methods need to be improved as well to enhance drivers' compliance and to prolong the lifespan of bridges. The report concluded by providing recommendations that can improve the notification and enforcement systems to effectively communicate and administer bridge load postings

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
APT	Air Pressure Transducer
ASR	Allowable Stress Rating
ATMS	Advanced Traffic Management System
AVI	Automatic Vehicle Identification
AVL	Automated Vehicle Locator
BASt	German Federal Highway Research Institute
BDEM	Bridge Design and Evaluation Manual
BIRM	Bridge Inspection and Rating Manual
BME	Bridge Management Engineer
BRRC	Belgian Road Research Center
BSIPM	Bridge and Structure Inspection Program Manual
B-WIM	Bridge Weigh-in-Motion
CAV	Connected and Automated Vehicle
CCTV	Closed-Circuit Television
CET	Cold Environmental Test
CMS	Changeable Message Sign
CMT	Continental Motorway Test
CMV	Commercial Motor Vehicle
CVINS	Commercial Vehicle Information Systems and Networks
CVO	Commercial Vehicle Operations
DA	District Administrator
DMS	Dynamic Message Sign
DMV	Department of Motor Vehicles
DOT	Department of Transportation
DPS	Department of Public Safety
DWL	Dynamic Wheel Loads
FAD	Free-of-Axle Detector

FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GVW	Gross Vehicle Weight
HAR	Highway Advisory Radio
HS-WIM	High speed Weigh-in-Motion
IEEE	Institute of Electrical and Electronics Engineers
IRB	Institutional Research Board
ISWIM	International Society of Weigh-in-Motion
ITS	Intelligent Transportation Systems
LA	Louisiana
LADOTD	Louisiana Department of Transportation and Development
LFR	Load Factor Rating
LRFR	Load and Resistance Factor Rating
LSU	Louisiana State University
LS-WIM	Low speed Weigh-in-Motion
MAP	Motorist Assistance Patrol
MassDOT	Massachusetts Department of Transportation
MBE	Manual for Bridge Evaluation
MDT	Montana Department of Transportation
MnDOT	Minnesota Department of Transportation
MS WIM	Multiple Sensor Weigh in Motion
MUTCD	Manual of Uniform Traffic Control Devices
NBIS	National Bridge Inspection Standards
NOR	Nothing-on-the-Road
OBW	On-Board Weighing
PI	Principal Investigator
POE	Points of Entry
PRC	Project Review Committee
PTZ	Pan, Tilt, and Zoom
RMS	Ramp Metering System

RSU	Road Side Unit
SHP	State Highway Police
SHV	Special Hauling Vehicle
SIM	Stress-in-Motion
SMS	Structure Management System
TMC	Traffic Management Center
Tran-SET	Transportation Consortium of South-Central States
T2	Technology Transfer
TRR	Transportation Research Record
US	United States
USA	United States of America
VDS	Vehicle Detection System
WIM	Weigh in Motion
ZAG	Slovenian National Building and Civil Engineering Institute

EXECUTIVE SUMMARY

Bridges are considered one of the most vital elements of transportation infrastructures. Indeed, bridges are expensive to construct and even more expensive to rehabilitate. Therefore, state, and local law enforcement agencies in the US and elsewhere strive to enforce weight restrictions on trucks and heavy vehicles travelling on public roads as a matter of public safety and as a way of safeguarding vital transportation infrastructure. For instance, vehicles over 40 tons are not permitted on interstate highways under normal conditions. Moreover, other restrictions can be applied based on the legal load combination, a function of vehicle weight and axle spacing.

The Louisiana Department of Transportation and Development (LADOTD) has a total of 13,000 bridges: 8,000 on-system bridges (state-owned) and 5,000 off-system bridges (local entity owned) which require significant resources to maintain and replace. In general, bridge owners have three critical tasks in common:

- Inspect the bridge for deterioration or damage.
- Determine if changes in condition have reduced the bridge's structural capacity to safely carry legally permissible loads, measured by its load rating; and
- Notify the public of any weight restrictions.

Therefore, it is important to regularly inspect and maintain them in order to prolong their serviceability and life cycle. According to the National Bridge Inspection Standards (NBIS), a bridge owner shall conduct load rating analysis on bridges at least once every two years (1). Weight restrictions could be applied on bridges based on the results of the analysis.

There are many methods by which bridge owners and relevant government entities such as Department of Transportation (DOT) can notify the public of any weight limit restrictions. However, public notification only is not enough as not all drivers may adhere and comply with such postings. Hence, law enforcement agencies must work together with bridge owners and relevant government agencies to enforce bridge load posting and make sure that truck drivers are obeying the legal load limits using numerous enforcement systems.

Unfortunately, the bridge infrastructure is deteriorating faster than resources will allow for rehabilitation and replacement. As bridges deteriorate/age and live load increases due to industry demand for larger and heavier trucks, the load carrying capacity of the structure decreases, therefore load posting is required to ensure public safety.

Therefore, the main objectives of this research are to:

1. Identify plausible notification systems that effectively communicate bridge load postings to dispatchers and drivers.
2. Investigate and suggest possible approaches to communicate potential detour routes.
3. Identify corresponding enforcement methods required to successfully administer bridge load postings.

To achieve the objectives of this research, a national online survey was developed that targeted State DOTs and various law enforcement agency including the Department of Public Safety (DPS), State Highway Police (SHP) and Department of Motor Vehicles (DMV) in the 50 States within the United States. This survey focused on identifying the current standards used by US States to conduct bridge load rating analysis, the existing methods used to notify the public of weight restrictions on bridges as well as the limitations of these systems and plans for future improvement. This survey also aimed to find out the current enforcement methods used by US States to ensure the public compliance of weight restriction on bridges, the frequency of using these enforcement methods, and its limitations. The survey was developed after reviewing State DOT guidelines related to bridges, and previous publications about bridge load notification and enforcement.

Moreover, a review of the best practices in bridge load notification methods used nationally and bridge load enforcement methods used internationally such as in Switzerland, Germany, Slovenia, Netherlands, Belgium and France was conducted. The review aimed to evaluate the effectiveness of the different systems used for bridge load posting notification and enforcement and to identify any challenges associated with them. Furthermore, a review was conducted to evaluate the existing conditions of ITS technologies and devices in Louisiana.

The results of the online survey indicated that majority of the States (around 90%) use the Manual for Bridge Evaluation (MBE) as their specification for bridge load rating. However, not all the States comply with the NBIS's recommended frequency to administer bridge load rating. NBIS recommends administering bridge load rating analysis once every two years. However, according to the survey results, only around 13% of the participating states comply with this recommendation.

Furthermore, it was reported that approximately 80% of the States follow the Manual on Uniform Traffic Control Devices (MUTCD) as guidance for load posting signages. The analysis also showed that more than 75% of the States use at least one other notification method in addition to positing signs such as online posting (website / mobile), 511 system, printed materials (booklet/map). Considering the results of this research, the limitations of existing notification systems could be categorized under the following:

- Driver related: such as drivers' incompliance with posted weigh limit.
- Signage related: such as damaged or missing load posting signs.
- Technology related: such as lack of online posting tool
- Resource / administration related: such as lack of communications between bridge owners and stakeholders, or
- Awareness related: such drivers' unfamiliarity with weight conversions as signs indicate weight in tons while it is common practice in the industry to indicate weight in thousands of pounds.

By addressing these limitation, the existing notification methods can be improved to reach a larger range of drivers, provide accurate and detailed information in real time so drivers can better plan their trip before they are on the road.

To identify possible approaches to be used for communication of potential detour plans, many alternatives were assessed. These alternatives were categorized into pre-route and en-route options, then a comparison between the advantages and disadvantages of these alternatives were made to assess their functionality. It was concluded that pre-route options such as website posting, and 511 phone system can provide more information and reach a larger group of drivers, however, smartphone/internet access is required. While en-route options including portable CMS and portable HAR can provide concise information to drivers without requiring them to use smartphone while driving which could reduce traffic safety and may lead to accidents. Furthermore, the portability function of CMS and HAR allow them to be used at different site locations whenever required.

The review of best practices related to size and weight enforcement, indicated that traditional methods (manual inspection using measuring tape for size enforcement and static weighing for weight enforcement) have a lot of limitations such as being time consuming, and the documentation process is open to errors. Using state of the art technologies has a lot of advantages that can overcome many of the limitations caused by the traditional methods. Regarding weight enforcement, static weighing is commonly used for direct enforcement due to its accuracy. However, it is not ideal to subject all trucks to undergo static weighing inspections as the process is time consuming and requires a lot of resources in terms of manpower and space to conduct the inspection. Therefore, Weigh in Motion (WIM) technology is either used as a pre-selection method for possibly overweighed vehicles that need to go through further static weighing inspection. It was found that this was the procedure used in many countries such as Slovenia, Switzerland, and Netherlands. In addition, a direct enforcement method (especially low-speed WIM) for overweigh violation is used in France, Germany, and United Kingdom.

The survey results indicate that static weighing is used in more than one third of the States (34.1%) for weight enforcement. While less than half of the States (46.2%) that use WIM are using the system for direct enforcement of overweigh violation. Also, the survey findings revealed that approximately 70% of the States conduct weight enforcement either daily or a few times per week. To improve the enforcement methods, States need to utilize the emerging technologies in size and weight enforcement as they can inspect more vehicles in shorter time compared to the traditional methods. Using static weighing only is not effective as the officer will only administer static weighing after visually suspecting a vehicle to be possibly overweight, however, WIM systems can assess and inspect all the vehicles on the road segments and flag vehicles that require further inspection (using static weighing for example). Furthermore, increasing enforcement methods and the number of enforcement frequencies will lead to efficiently testing more vehicles and possibly capturing more violators.

1. INTRODUCTION

The Louisiana Department of Transportation and Development (LADOTD) has a total of 13,000 bridges: 8,000 on-system bridges (state-owned) and 5,000 off-system bridges (local entity owned) which require significant resources to maintain and replace. State and local law enforcement agencies in the United States (US) strive to enforce weight restrictions on trucks and heavy vehicles travelling on public roads as a matter of public safety and as a way of safeguarding vital transportation infrastructure.

This report discusses the existing conditions of intelligent transportation systems in Louisiana, the best practices used to conduct bridge load rating analysis, current bridge load posting notification and enforcement methods. Furthermore, an online survey was prepared that targeted State DOT professionals and law enforcement agencies personnel in USA to gather their feedback and insights regarding the existing bridge loads notifications and enforcement systems at their States.

According to NBIS, after constructing a bridge, it shall be inspected once every two years as part of every bridge owner's responsibility (1). The main purpose from such inspection is to document any deterioration or damage that might reduce capacity. Accordingly, an updated load rating analysis might be recommended.

When the operating level rating factor of a bridge is less than 1 for a given legal load combination, the bridge no longer has the capacity to carry that full legal load. As this puts the safety of drivers at risk, the bridge owner must restrict truck weights. This can be done through a load posting, until such time that structural capacity of the bridge is restored, or the bridge is no longer able to carry traffic.

the Federal Highway Administration (FHWA) stated that in order to minimize the loss of access to a bridge, agencies responsible for postings restrictions need to adopt additional strategies for reducing negative impacts and barriers to enforcement including (2):

- Identify and share alternate routes available to heavy vehicles.
- Use an advance posting so commercial vehicles can take an alternate route without backtracking; and
- Communicate the new posting and risk of overloading the bridge to the public.

Unfortunately, the bridge infrastructure is deteriorating faster than resources will allow for rehabilitation and replacement. As bridges deteriorate/age and live load increases due to industry demand for larger and heavier trucks, the load carrying capacity of the structure decreases, therefore load posting is required to ensure public safety.

Therefore, FHWA requires that to effectively manage the risk of a bridge failure due to overload, agencies responsible for postings restrictions must (2):

- Have a load rating for all bridges in their inventory that considers the current condition of the bridge and all legal load combinations.
- Post weight restrictions at any bridge that cannot safely carry legal loads; and
- Work with law enforcement to ensure weight restrictions are enforced.

2. OBJECTIVES

The objectives of our project can be summarized as follows:

1. Identify and suggest plausible notification systems that effectively communicate bridge load postings to dispatchers and drivers.
2. Investigate and suggest possible approaches to communicate potential detour routes.
3. Identify corresponding enforcement methods required to successfully administer bridge load postings

It is expected that the outcomes of this research will assist in developing an effective mechanism to communicate and enforce load restrictions on bridges. This is crucial to provide the appropriate level of safety for those utilizing these bridges especially on daily basis.

Figure 1 illustrates the overall methodology used in this study to achieve the abovementioned objectives. Each of these tasks will be explained in detail in the following sections.

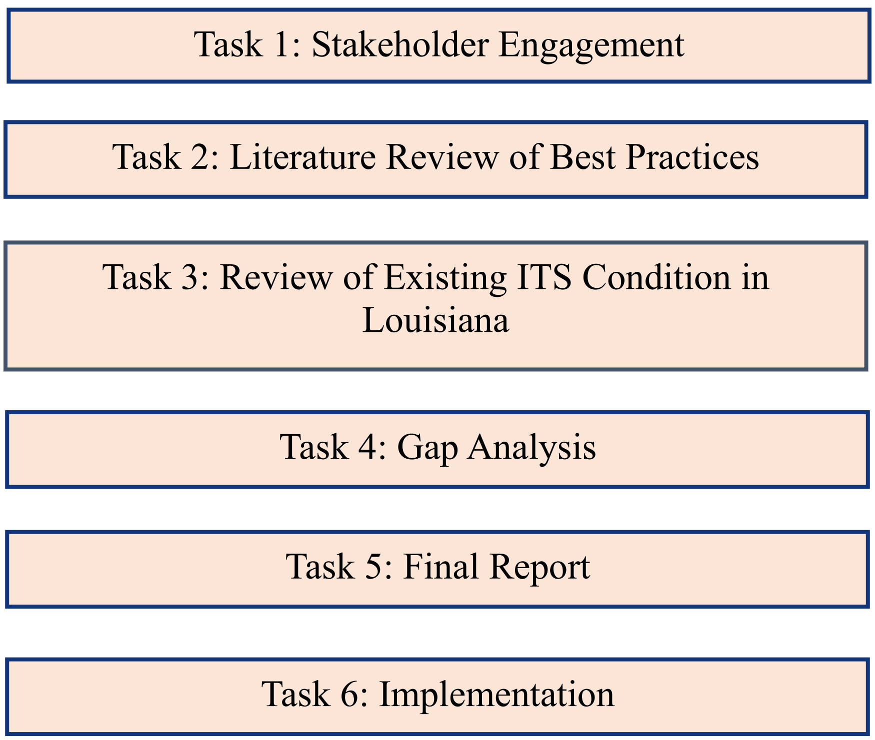


Figure 1. Overall Project Methodology

3. LITERATURE REVIEW

To meet the project requirements, the literature review is divided into three sections as follows:

- Section 1: discusses the current notification systems and possible approaches to communicate potential detour routes,
- Section 2: discusses the current enforcement systems,
- Section 3: discusses the current ITS conditions in Louisiana.

3.1. Notification System:

3.1.1. Load Rating:

The Manual for Bridge Evaluation (MBE) published by the American Association of State Highway and Transportation Officials (AASHTO) defined load rating as the “live-load carrying capacity of an existing bridge” (3).

In July 2018, the Federal Highway Administration (FHWA) published a video titled Bridge Load Rating and Posting combined with a guide under the same title that explain the video in more details, the video can be accessed via this link: https://www.fhwa.dot.gov/federal-aidessentials/catmod.cfm?id=119. The video and the guide were released under the FHWA’s Bridge Program to safely promote and increase the serviceability of bridges especially deficient ones (2).

According to FHWA, the responsibility of bridge owners (whether it was the State or a private owner) does not end after constructing the bridge, and it is open for live traffic. In fact, they have more responsibilities to take care of after the bridge is open than before it is constructed. Their main objective is to ensure that the bridge is safe to be used by the public during its operational life cycle. Since the capacity of any bridge to safely carry legally permissible loads weakens due to many factors over time; bridge owners should:

- Look for any signs of structural damage or deterioration,
- Conduct load rating to find out if the bridge’s structural capacity decreased due to the observed signs above, and
- Ensure that the public is aware of any weight restrictions if any.

In 2018, Minnesota Department of Transportation (MnDOT) released its latest Bridge Load Rating Manual. The Bridge This manual documented the procedures to administer and evaluate bridge load rating. Load rating includes various factors such as the current condition of a bridge and the changes of loading over time to estimate the bridge's current capacity. The load rating analysis is used to support bridge load posting and overweight permitting (4). According to the manual, federal law (23 CFR 650 Subpart C) mandates that all bridges over 20 feet in length must be inspected and have load rating analysis conducted according to the procedures specified in the AASHTO MBE. While further elaboration of the federal requirements is available on the Metrics for the Oversight of the National Bridge Inspection Program published by FHWA (4). Each state set out its on statutes that safeguard the rules and regulations governing bridge load posting.

3.1.2. Load Rating Analysis:

According to NBIS, it is the bridge owner's responsibility to inspect the bridge once every two years (1). The inspection is done to document any deterioration and damage and to conduct a load rating analysis that determines the existing bridges' live-load carrying capacity. This rating analysis is essential as it determines the capacity to carry live loads on the bridge that are very different in size and force effects than the original design's live load condition (4). The bridge will no longer have the capacity to carry the permissible bridge load if the operating rating factor is less than 1. If this happens, the drivers' safety will be at risk. So, the bridge owner must enforce truck weights with proper posting.

Bowman and Chou stated in their review of Load Rating and Posting Procedures and Requirements, that all states in the US are required to load rate and post bridge loads. They also mentioned that most states use the 2nd edition MBE by AASHTO for specifications of load rating and posting (5). According to the manual, there are three methods for load rating analysis:

- Allowable Stress Rating (ASR),
- Load Factor Rating (LFR), and
- Load and Resistance Factor Rating (LRFR).

Most of the states prefer both the LFR and LRFR methods. LRFR is the preferred method, however, LFR can be used if the maximum span length is less than 200 feet, and the ASR is used if the material is timber or corrugated steel (5).

To reduce the risk of bridge failure due to overloading, the responsible agencies should follow some strategies. They should consider the current condition and all legal load combinations on the bridge when conducting the load rating analysis. After the analysis, if a bridge cannot safely carry legal loads, weight restrictions should be posted. The agencies should closely work with law enforcement to ensure proper enforcement technology and procedures to enforce weight restriction (2).

The Bridge Design and Evaluation Manual (BDEM) by LADOTD stated that any public bridge or the 1st rating of any bridge must be rated in accordance with the LRFR method except for timber bridges that may be rating using LRFR or ASR (6).

3.1.3. Load Posting:

Referring to Montana Department of Transportation's (MDT) Bridge Inspection and Rating Manual Revision of the MDT's 2018 Bridge Inspection and Rating Manual, the result of the load rating analysis should be used for posting requirements. The load rating engineer shall recommend the posting based on these results. The Bridge Management Engineer (BME) makes the final determination on all load posting decisions, based on several considerations such as the bridge's physical condition, visible distress, structure redundancy, and traffic volume. The bridge may be closed in the interest of public safety if there is any concern that significant disregard of load posting will occur (7).

A bridge must be posted with weight restrictions if the load rating analysis for any legal loads finds the:

- Operating rating factor that is less than one based on ASR or LFR, or
- Rating factor is less than one based on LRFR.

The difference between operating rating factor and rating factor as defined by AASHTO is that the first term describes the maximum permissible live load to which a structure may be subjected while the second term is a resulting calculation from a load rating equation which is always associated with a particular live load (3).

If the load rating analysis concluded that posting is required on a bridge, posting load should be estimated based on every vehicle type. For both ASR and LFR methods, posting load is determined based on the calculated inventory rating which is live load (in tons) that can safely utilize an existing structure for an indefinite period (3). Whereas for the LRFR method there are two cases as follows:

- If the rating factor falls below 0.3, then that vehicle type should not be allowed on the bridge span.
- If the rating factor is between 0.3 and 1, then MBE Equation 6A.8.3-1 is used to calculate the safe posting load.

$$SPL = \left(\frac{W}{0.3}\right)[RF - 0.3] \qquad (MBE\ 6A.8.3-1)$$

Where,

$SPL = Safe\ Posting\ Load\ (in\ Tons)$

$W = Weight\ of\ Rating\ Vehicle\ (in\ Tons)$

$RF = Vehicle\ Rating\ Factor$

The threshold of 0.3 corresponds to the truck's empty weight, the bridge may need restrictions or closure if it cannot support the weight of empty trucks. The minimum permissible posting is three tons, and if a bridge cannot carry a minimum gross live load of three tons, it must be closed. A bridge may also be posted for non-load related conditions like maximum speed, the maximum number of vehicles, etc.

When determining the posting load using any of the methods stated above, the resulting value is considered conservative since it is the lower bound of safe load capacity. However, sometimes these values are too conservative. Therefore, engineering judgement is used to minimize the unnecessary closures of bridges with rating factors that are considered too conservative. Such bridges are reviewed on a case-by-case basis and the revision needs to document the consideration behind it as well as the approval of the BME (4).

- For ASR and LFR, engineering judgement is used to select the appropriate posting load between the inventory rating that is the lower bound of safe load capacity and the operating level which is the maximum permissible live load to which a structure may be subjected which also the maximum bound of safe load capacity (3).

- For LRFR, engineering judgement is used to select the appropriate posting load between the MBE Equation 6A.8.3-1 that is considered the lower bound of safe load capacity and the maximum safe load capacity which is based on MBE Equation 6A.4.4.4-1 (3).

$$SLC = RF \times W \qquad (MBE\ 6A.4.4.4 - 1)$$

where,

$SLC = Safe\ Load\ Capacity\ (in\ Tons)$

$RF = Vehicle\ Rating\ Factor$

$W = Weight\ of\ Rating\ Vehicle\ (in\ Tons)$

3.1.4. Posting Procedure:

MDT outlined in their BIRM the steps to be followed to properly complete the posting procedure after a decision is made about posting load restriction or closure of a bridge since it is the bridge owner's responsibility to install necessary postings like signage and barricades as mentioned earlier (7).

If the State DOT owns the structure, the need for posting is identified, and a load posting form is completed. The bridge management engineer will notify the District Administrator (DA), engineers, and other appropriate personnel and work closely to ensure proper signages. The DA is responsible for choosing a sign option from the load posting form and coordinating to implement the posting or closure. Once the proper signs and barricades are in place, the BME will verify it and upload the documentation to the Structure Management System (SMS). For the long term, routine bridge inspections will verify posting (or non-posting) (7).

However, if the structure is owned by a private owner and once the need for posting is identified and a load posting form has been completed, a letter from the BME shall be sent via email to the bridge owner within 48 hours. The letter should consist of the reason for posting and additional information to facilitate proper posting. The letter will include a description and photos detailing the problem if bridge closure is required. Then the bridge owner is responsible for choosing an acceptable sign option from the load posting form and implementing posting or closure of the bridge. Once the proper signs and barricades are in place, the BME will verify it and upload the documentation to the SMS. If the bridge owner does not contact the engineer within two days, the owner will be contacted again. If no response is received, the DOT will choose the sign option and implement the posting. For the long term, routine bridge inspections will verify posting (or non-posting) (7).

Once a posting is established, it cannot be removed or improved without the BME’s written approval. It would require some level of strengthening to rescind postings. After a bridge is strengthened, a request can be sent to the BME with updated structural information to rescind the posting. The Bridge management personnel will investigate it and will recommend whether to approve the rescind or revise load posting (7).

3.1.5. Posting Signage:

The load posting signage and installation should comply with the Manual of Uniform Traffic Control Devices (MUTCD) and DOT detailed drawings. Advanced posting signs may also be required at nearest roads or ramps leading towards bridges requiring posting or closure.

When determining posting signage, consideration should be given to practical limitations. The sign selection should be limited to all necessary vehicles only. It should not reduce the mobility of other vehicles that the load restriction does not apply to them (7).

The Arizona Department of Transportation (ADOT) published the ADOT Bridge Load Rating Guidelines in 2018 to establish uniform regulations that is consistently applied throughout the State. The guidelines indicated that posting signages shall conform with the MUTCD. Sample posting signs taken from the ADOT guidelines are shown in Figure 2 through Figure 4 below (8).

Figure 2. Load Posting Sign for Legal Load (Source: ADOT Bridge Load Rating Guidelines)

Figure 3. Load Posting Sign for Special Hauling Vehicle (SHV) Load (Source: ADOT Bridge Load Rating Guidelines)

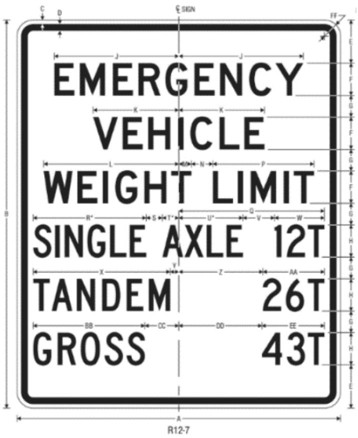


Figure 4. Load Posting Sign for Emergency Vehicle Load (Source: ADOT Bridge Load Rating Guidelines)

In 2021, the Bridge and Structure Inspection Program Manual (BSIPM) by MnDOT was published as a comprehensive and uniform reference in inspecting and documenting bridge conditions within the State. MnDOT has its own MUTCD that conforms with the federal MUTCD by AASHTO. Figure 5 shows some examples of load posting signs applied within the State of Minnesota (9).

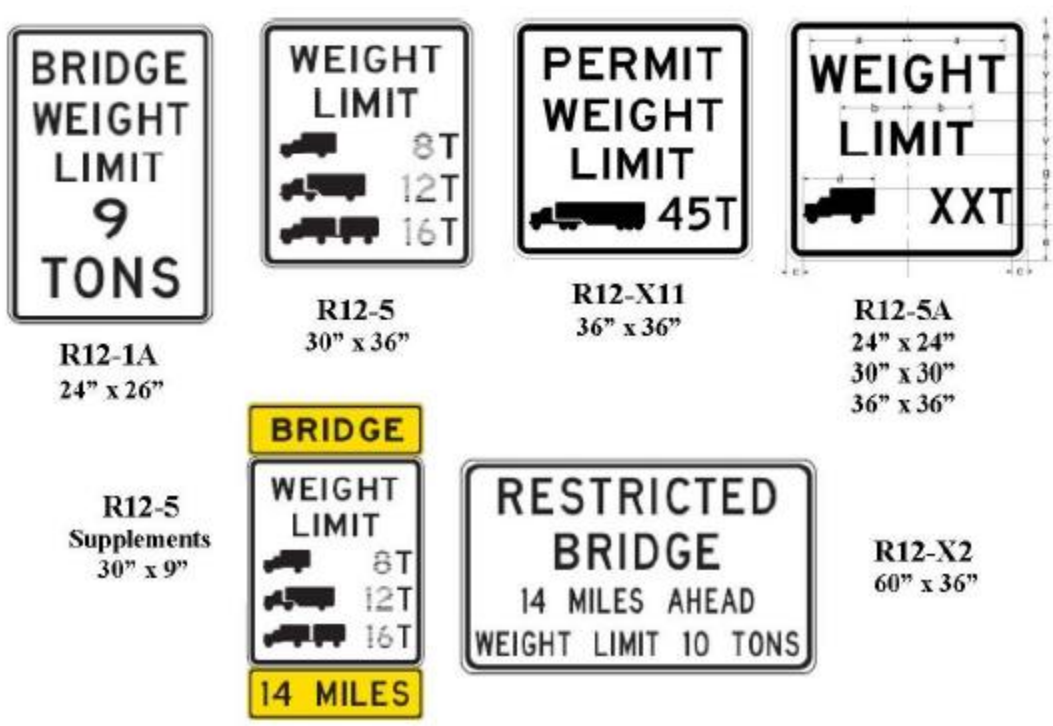


Figure 5. Load Posting Signs (Source: BSIPM by MnDOT)

As mentioned earlier, non-load restrictions could be applied on bridges. For example, a bridge inspection may indicate that speed limit restriction is required in which case sign R2-X5 of Minnesota MUTCD is installed 100 ft before each end of the bridge as shown in Figure 6 below.

Figure 6. Bridge Speed Limit Sign R2-X5 (Source: Minnesota MUTCD)

Other restrictions could include sign R12-X3/R12-X3A that display “Trucks/Vehicles Must Not Meet on Bridge” shown in Figure 7 below, among other types of restriction that are in place to ensure public safety (9).

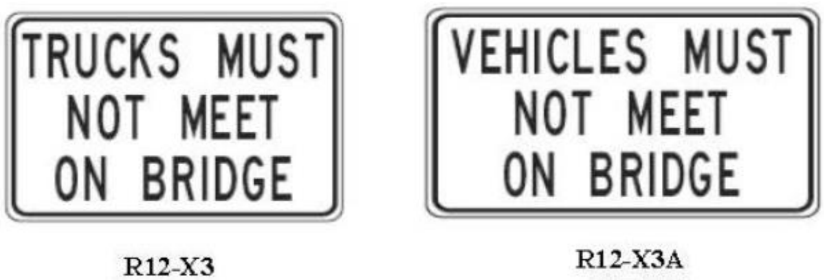


Figure 7. Sign R12-X3/R12-X3A (Source: Minnesota MUTCD)

3.1.6. Online Posting:

Generally, FHWA maintains a database of each State’s bridge data that are submitted by each State annually in accordance with the NBIS. The database includes detailed information of all the bridges within the state such as the bridge owner, dimensions, location, coordinates, any weight or height restrictions, built year, design load, Average Daily Traffic (ADT), Annual Average Daily Traffic (AADT), maintenance history and safety rating. These datasets can be accessed via this link: https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm (10). Nevertheless, some states have online resources that provide bridges information to the public. Some of the webpages have interactive maps that show all the bridges within the state. By clicking on any bridge, detailed information will appear that includes posted load, any other restrictions (if any), bridge location, bridge owner, and other useful information. There is also a search option that allows for bridges that meet specific search criteria to be displayed on the map. The figures below show some examples of online posting methods that are being used by different State DOTs to notify the public of their bridge load posting/restrictions if applicable.

Alabama DOT posted a map that shows all the posted state bridges within the State as of November 2020, as shown in Figure 8 (11). While Maine DOT has both an online interactive map and a bridge inventory list that is categorized according to each city/town within the State as presented in Figure 9 and Figure 10 respectively (12–13). However, Maryland DOT has an online bridge inventory list that present information on height, weight, and under-clearance restrictions within the State. Figure 11 shows an example of a bridge information in Washington, Maryland (14). Moreover, Massachusetts Department of Transportation (MassDOT) also has online interactive map as shown in Figure 12 (15). Similarly, both Nebraska DOT and New York DOT also have online interactive maps that show the details of the posted bridges in their respective states as shown in Figure 13 - Figure 16 (16–17).

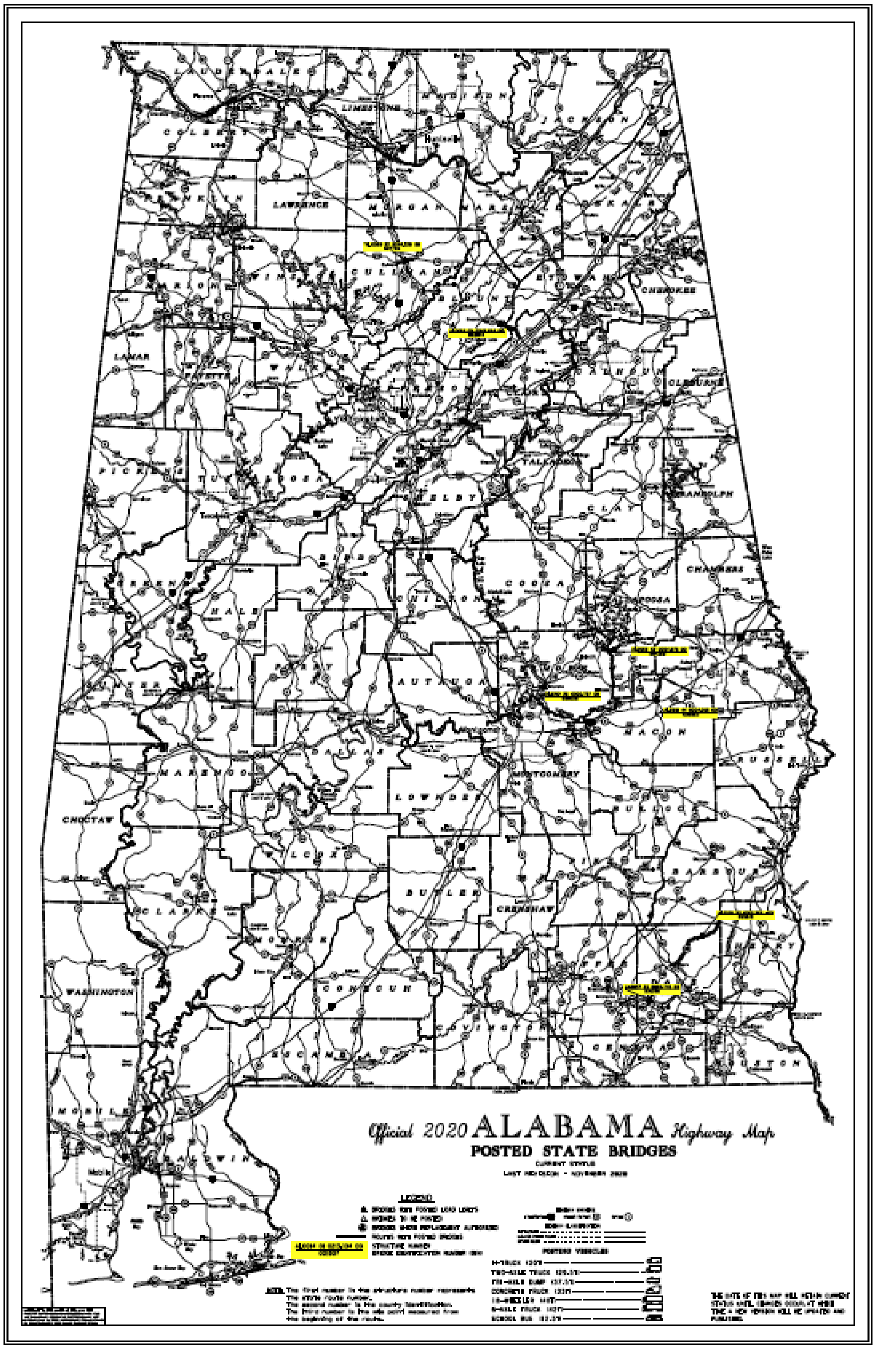


Figure 8. Alabama Map of Posted State Bridges (Source: Alabama DOT Website)

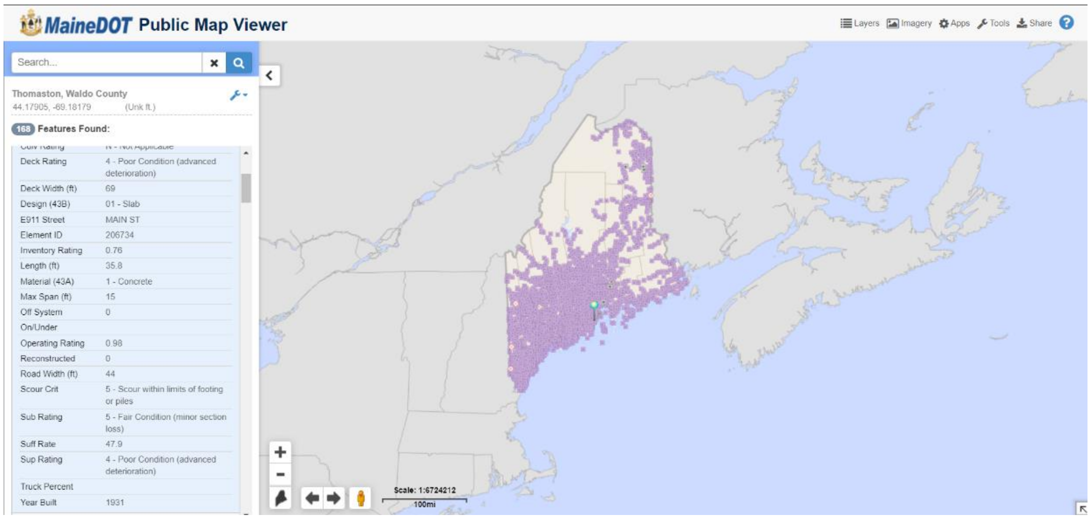


Figure 9. Maine Weight Restricted Bridges (Source: Maine DOT Website)

MAINE PUBLIC BRIDGE STRUCTURES IN THE MUNICIPALITY OF **Abbot**

Link to Map Viewer

IDENTIFICATION

Town	Abbot	Town2	No Town2
Bridge Name	LITTLE	Location	.3 MI E JCT 15 & 16
Bridge Number	0956	Route Number	2100651
Feature On	TOWN WAY	Bridge Region	4 - Eastern Region
Feature Under	OVERFLOW BROOK	Border Bridge	
Bridge Road Width (Feet)	0	Bridge or Minor Span	Minor Span on Town Way

CLASSIFICATION

Owner	Municipality	Maintainer	Municipality
Maximum Span Length (Feet)	13	Federal Bridge Indicator	N

AGE AND CONDITION

Deck Condition	N - Not Applicable	Culvert Condition	8 - No noticeable or noteworthy deficiencies
Superstructure Condition	N - Not Applicable	Channel Condition	6 - Bank slump. widespread minor damage
Substructure Condition	N - Not Applicable	Approach Condition	6 - Equal to present minimum criteria
Year Built	2006	Annual Average Daily Traffic	274

INSPECTION AND APPRAISAL

Date of Inspection	05/05/20	Federal Sufficiency Rating	86

STRUCTURE TYPE AND MATERIAL

Span Material	Concrete	Span Type	Culvert (includes frame culverts)
Number of Main Spans	1		

LOAD RATING AND POSTING

Posting Status	Open	Posted Weight (Tons)	
POSTING TYPE 4-Axle One-Truck Spacing			

1 of 6

Produced by MaineDOT Bridge Maintenance
October 1, 2020

Figure 10. Maine Bridge Inventory (Source: Maine DOT Website)

Washington County - Weight Restriction

Bridge No.	Route No.	Crossing	Single Unit Vehicle	Combination Vehicle
2102300	MD 56	Little Conococheaque Creek	24,000	24,000
2103800	MD 68	Antietam Creek	27,000	27,000
2103900	MD 68	Beaver Creek	27,000	27,000

Figure 11. Maryland Bridge Inventory by county (Source: Maryland DOT Website)

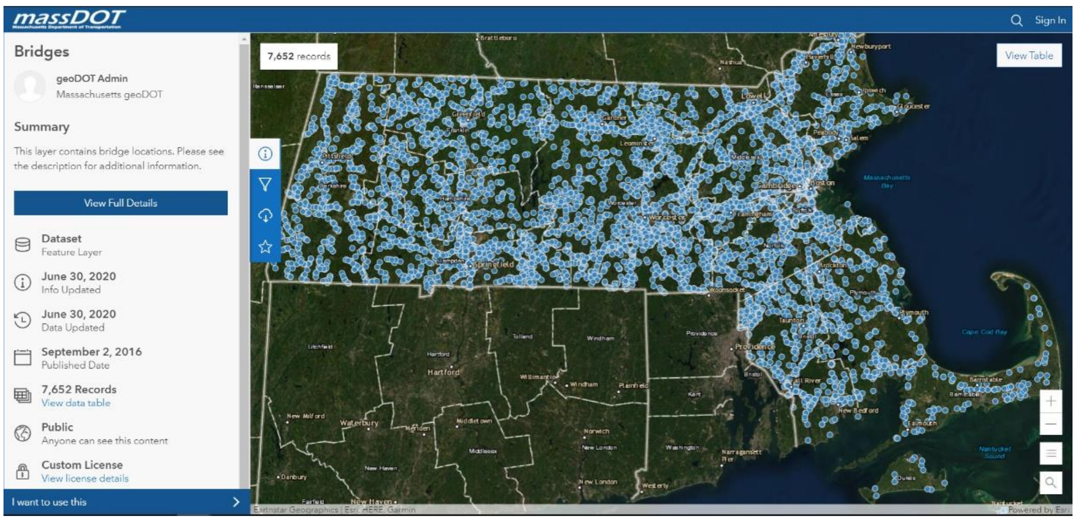


Figure 12. Massachusetts Weight Restricted Bridges (Source: Massachusetts DOT Website)

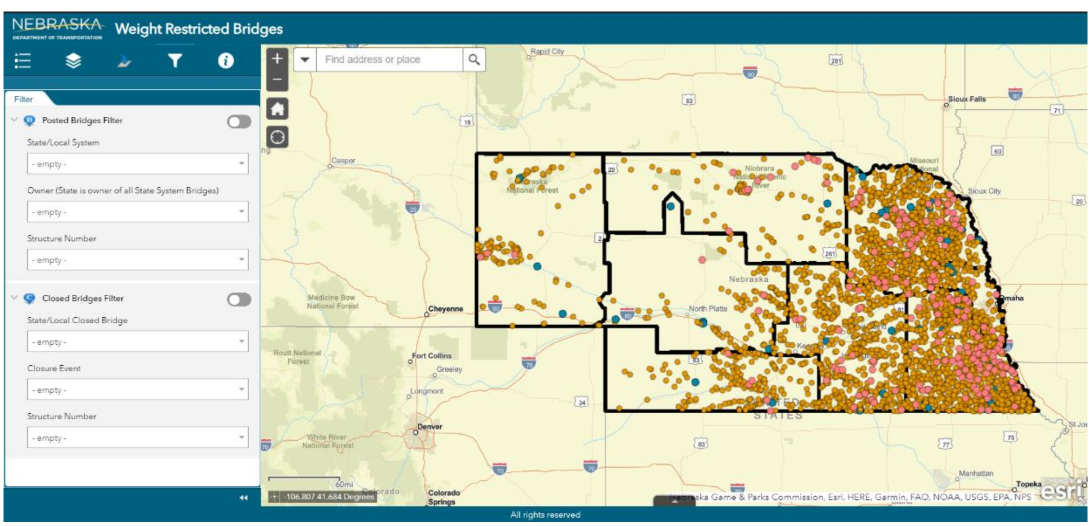


Figure 13. Nebraska Weight Restricted Bridges (Source: Nebraska DOT Website)

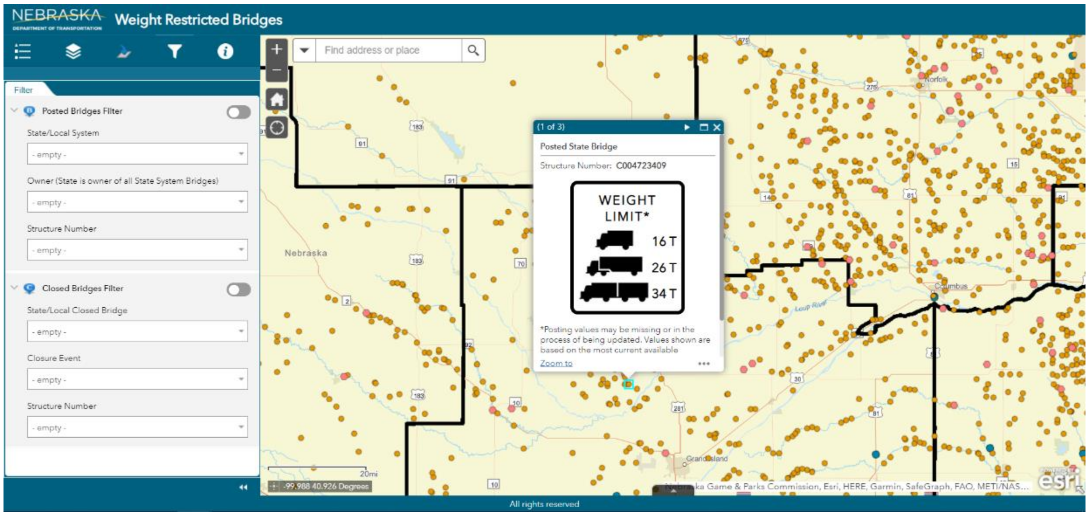


Figure 14. Posting Information of a bridge in Nebraska (Source: Nebraska DOT Website)

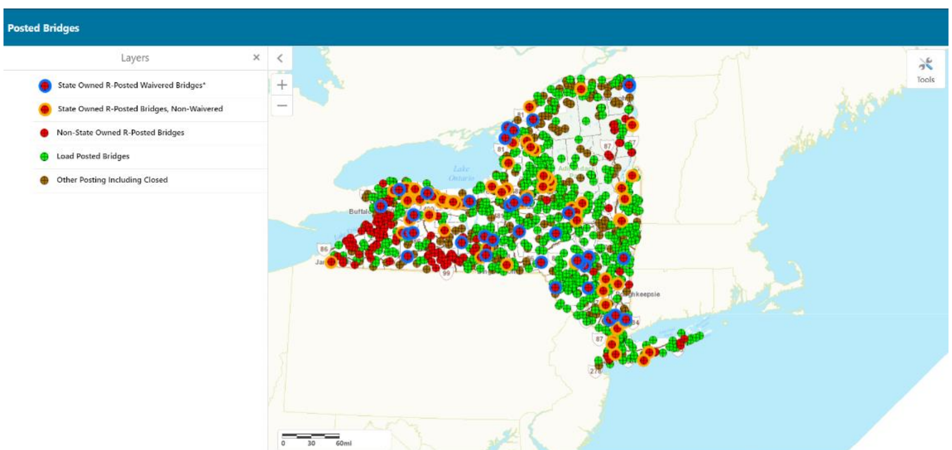


Figure 15. New York Posted Bridges (Source: New York DOT Website)

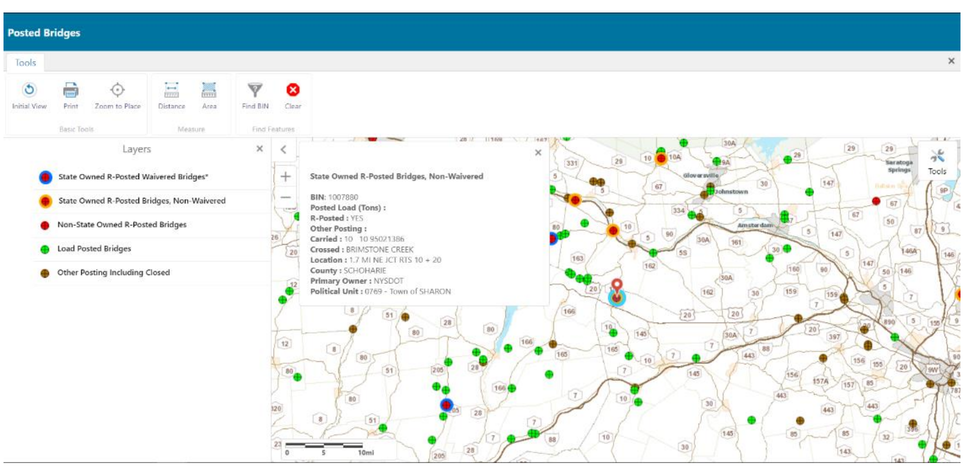


Figure 16. Detailed Information of a bridge in New York (Source: New York DOT Website)

Table 1 summarizes the availability of online posting in each US State including the type of online posting and a link to access the online resource if available.

Table 1. Status of Online Posting Availability in Each State

S.N.	State	Availability of Online Posting	Type of Online Posting	Link	Ref.
1.	Alabama	Yes	Map	https://www.dot.state.al.us/publications/Maintenance/pdf/Bridge/PostedBridgeMap.pdf	18
2.	Alaska	No	-	-	-
3.	Arizona	Yes	Inventory list	https://azdot.gov/business/engineering-and-construction/bridge/bridge-tunnel-inventory	19
4.	Arkansas	Yes	Interactive map	https://ardot.maps.arcgis.com/apps/webappviewer/index.html?id=0de1110c51944e408fcf5313867d65bd	20
5.	California	Yes	Inventory list	https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/f0009152-logd05-a11y.pdf	21
6.	Colorado	Yes	Interactive map	https://cdot.maps.arcgis.com/apps/MapSeries/index.html?appid=ebd01fcfd5f746eda81f8d3bfbc9adc2	22
7.	Connecticut	Yes	Inventory list	https://portal.ct.gov/DOT/Bridges/Bridge-Data	23
8.	Delaware	No	-	-	-
9.	Florida	Yes	Inventory list	https://www.fdot.gov/maintenance/bridgeinfo.shtm	24
10.	Georgia	No	-	-	-
11.	Hawaii	Yes	Inventory list	https://geoportal.hawaii.gov/datasets/9a9e1f840dc84b9a9b25775f2d7e0acf_9/explore?location=13.171690%2C23.291602%2C4.55	25
12.	Idaho	No	-	-	-
13.	Illinois	Yes	Inventory list	http://apps.dot.illinois.gov/bridgesinfosystem/search.aspx	26
14.	Indiana	Yes	Interactive map	https://indot.maps.arcgis.com/apps/webappviewer/index.html?id=0a27953c1ae7480eae1c8fdd4c6b8e28	27
15.	Iowa	Yes	Inventory list	https://iowadot.gov/mvd/motorcarriers/embargolist.pdf	28

S.N.	State	Availability of Online Posting	Type of Online Posting	Link	Ref.
16.	Kansas	Yes	Map	https://www.ksdot.org/Assets/wwwksdotorg/bureaus/burTransPlan/maps/BridgeMaps/2021/ksbridgerestrictionmap.pdf	29
17.	Kentucky	Yes	Interactive map	https://maps.kytc.ky.gov/bridgeweightlimits/	30
18.	Louisiana	Yes	Interactive map	https://ladotd.maps.arcgis.com/apps/mapviewer/index.html?webmap=d71ca381985149ba920ca6fb1683ebf7	31
19.	Maine	Yes	Interactive map	https://www1.maine.gov/mdot/mapviewer/?show=Bridges%20-%20All&q=Abbot	32
20.	Maryland	Yes	Inventory list	https://www.roads.maryland.gov/mdotsha/pages/Index.aspx?PageId=160	33
21.	Massachusetts	Yes	Interactive map	https://geo-massdot.opendata.arcgis.com/datasets/8fa67bf47651417283813a29bfc31545_0?geometry=-75.886%2C41.357%2C-67.542%2C42.784	34
22.	Michigan	Yes	Inventory list	https://www.michigan.gov/mdot/0,4616,7-151-47418-173571--F,00.html	35
23.	Minnesota	Yes	Interactive map	https://mndot.maps.arcgis.com/apps/webappviewer/index.html?id=458be6fe9acf4131a35455cc63702068	36
24.	Mississippi	Yes	Interactive map	https://mdot.ms.gov/portal/posted_bridges	37
25.	Missouri	Yes	Map	https://www.modot.org/Bridges	38
26.	Montana	Yes	Interactive map	https://mdt.maps.arcgis.com/apps/MapSeries/index.html?appid=ae0083bed62049b49b1011361159408f	39
27.	Nebraska	Yes	Interactive map	https://gis.ne.gov/portal/apps/webappviewer/index.html?id=f6945569f00a43268462568591475ab8	40
28.	Nevada	No	-	-	-
29.	New Hampshire	Yes	Interactive map	https://nh.maps.arcgis.com/apps/webappviewer/index.html?id=19bbd01f7af94a839d5ccddf9c3fcda1	41
30.	New Jersey	No	-	-	-

S.N.	State	Availability of Online Posting	Type of Online Posting	Link	Ref.
31.	New Mexico	Yes	Map	https://dot.state.nm.us/content/dam/nmdot/trucking/2012_bridge_map.pdf	42
32.	New York	Yes	Interactive map	https://gis.dot.ny.gov/html5viewer/?viewer=postedbridges	43
33.	North Carolina	Yes	Interactive map	https://www.arcgis.com/apps/mapviewer/index.html?webmap=db3b56c3228743b3811e36761393d661	44
34.	North Dakota	Yes	Map	https://www.dot.nd.gov/divisions/planning/freight/docs/NDFreightConstraintsMap.pdf	45
35.	Ohio	Yes	Inventory list	https://biareports.dot.state.oh.us/	46
36.	Oklahoma	No	-	-	-
37.	Oregon	No	-	-	-
38.	Pennsylvania	Yes	Interactive map	https://gis.penndot.gov/paprojects/BridgeConditionsMap.aspx	47
39.	Rhode Island	Yes	Interactive map	https://ridot.maps.arcgis.com/apps/OnePane/basicviewer/index.html?appid=1dc6adfa291146b8961fb420ac7eacdb	48
40.	South Carolina	No	-	-	-
41.	South Dakota	No	-	-	-
42.	Tennessee	Yes	Inventory list	https://www.tn.gov/content/dam/tn/tdot/documents/CentralServices/WEIGHT-POSTED-STATE-ROUTE-STRUCTURES.pdf	49
43.	Texas	Yes	Interactive map	https://www.txdot.gov/apps/statewide_mapping/statewideplanningmap.html	50
44.	Utah	No	-	-	-
45.	Vermont	Yes	Interactive map	https://vtrans.maps.arcgis.com/apps/webappviewer/index.html?id=968633edde4d40f6b5150d4393b9b1ff	51
46.	Virginia	Yes	Interactive map	https://vdot.maps.arcgis.com/apps/webappviewer/index.html?id=00cccfd4ef0a44ac84916295d41b87c3	52
47.	Washington	No	-	-	-
48.	West Virginia	No	-	-	-
49.	Wisconsin	No	-	-	-
50.	Wyoming	Yes	Interactive map	https://apps.wyoroad.info/itsm/map.html	53

Table 1 indicates that around 40% of the State DOTs have online posting in the form of interactive maps, while 22% provide inventory of bridges with restrictions. Moreover, 10% of the State DOTs do have online posting in the form of PDF map. Finally, there are 28% State DOTs that do not have any type of online posting as shown in Figure 17 below.

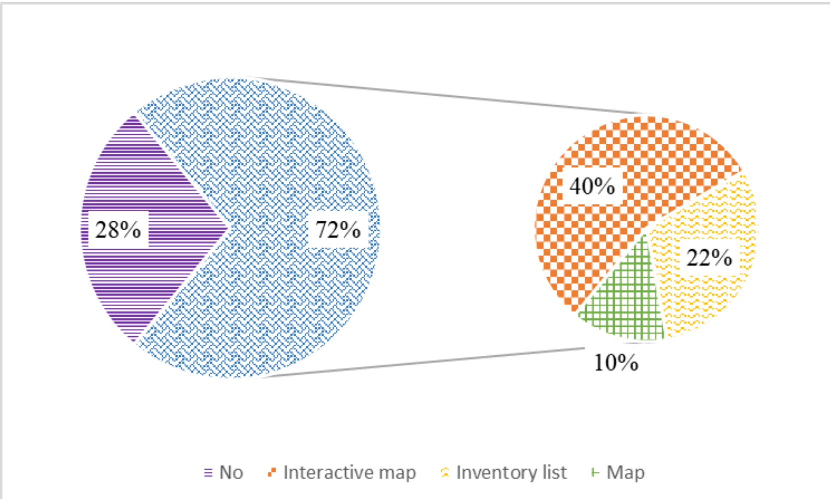


Figure 17. Availability of Online Posting in the US

3.1.7. Possible Approaches to Communicate Potential Detour Plans:

Relevant stakeholders including bridge owners and State DOTs need to notify the public about bridges that may be closed permanently if a bridge can no longer handle live traffic or temporarily if the bridge needs to be closed for some time until rehabilitation or maintenance is completed, and the structural capacity is improved. In this regard, potential detour routes may be suggested while rehabilitation work is ongoing. By considering a bridge under rehabilitation as work zone area, many methods used in work zone traffic management can be utilized as potential methods for information dissemination of alternative routes. These methods can be divided in two categories (54):

- **Pre-route: where drivers have access to the information before they plan their trip:**
  - Using DOT website to notify the public of closed bridges and alternatives to be used.
  - 511 phone services, drivers can call in advance and inquire about current detour plans.
  - Mobile apps including DOT applications or navigations maps applications.
  - Posting detour plans on official DOT social media accounts such as Twitter feed or Facebook posts.
- **En-Route: where drivers have access to the information while they are on the road:**
  - Changeable Message Signs (CMS): These electronic signs can be used in real time to inform drivers of possible detour plans. Portable CMS is recommended over permanent CMS because of feasibility and functionality since portable CMS can be moved and used in different locations. However, if a permanent CMS is available near a detour site,

then it is recommended to be utilized in addition to portable CMS. Figure 18 Shows an example of permanent CMS (54).

- Highway Advisory Radio (HAR): the system can be utilized to provide the public with possible detour alternatives by transmitting the information in real time to the vehicle's radio system via dedicated radio frequencies when the vehicle is near a HAR system. An example of HAR notification methods is shown in Figure 19 below (55).
- Traffic signs: using advanced posting at multiple locations will help drivers to reroute and save a lot of time instead of reaching to the closure location and having to discover that the bridge is closed.
- 511 phone services, drivers can still call while en-route and inquire about current detour plans.
- On vehicle navigation systems can also be used to disseminate potential detour plans.

Figure 18. An Example of CMS used for Information Dissemination (Source: FHWA's Alternate Route Handbook)

Figure 19. An Example of HAR sign used for Information Dissemination (Source: FHWA's Freeway Management and Operations Handbook)

The advantages and disadvantages of the different information dissemination methods of potential detour plans can be summarized in

Table 2 below. Looking at the table, it is recommended that portable CMS or portable HAR methods to be used as they can be moved to various locations when required and since information can be updated in real time as required.

It is also recommended that drivers utilize State DOT website, 511 phone service, mobile/navigation app, or official social media accounts before starting their trip only due to safety concerns of using their smartphone while driving. They may access these methods en-route if they stop in a safe location outside the roadway, for example in a parking lot.

Table 2. Advantages and Disadvantages of Various Information Dissemination Methods

S.N.	Information Dissemination Methods	Access Availability	Advantages	Disadvantages
1.	State DOT Website	Pre-trip and En-Route	- Can provide more information about the detour plan - Information can reach larger group of drivers	- Requires smartphone and internet access - Safety concerns if used by drivers during en-route
2.	511 Phone Service	Pre-trip and En-Route	- Can provide more information about the detour plan - Information can reach larger group of drivers	- Requires phone access - Safety concerns if used by drivers during en-route
3.	Mobile / Navigation App	Pre-trip and En-Route	- Can provide more information about the detour plan - Information can reach larger group of drivers	- Requires smartphone and internet access - Safety concerns if used by drivers during en-route
4.	Official Social Media Accounts	Pre-trip and En-Route	- Can provide more information about the detour plan - Information can reach larger group of drivers	- Requires smartphone and internet access - Safety concerns if used by drivers during en-route
5.	CMS	En-Route	- Portable CMS can be used in different locations - Different information can be displayed if necessary - Requires low power source (i.e. solar)	- Can provide limited information about the detour plan - Information can only reach drivers nearby the CMS sign - Requires attention on the road for CMS signs

S.N.	Information Dissemination Methods	Access Availability	Advantages	Disadvantages
			- Improved safety as no smartphone use or internet access is required	- Requires communication equipment, power source and regular maintenance
6.	HAR	En-Route	- Portable HAR can be used in different locations - Can provide more information about the detour plan - Requires low power source (i.e. solar) - Improved safety as no smartphone use or internet access is required	- Information can only reach drivers nearby the HAR range - Requires attention on the road for tune in instruction signs - Requires communication equipment, power source and regular maintenance - Radio signal could be interfered with due to changing weather conditions
7.	Traffic Signs	En-Route	- Inexpensive notification method - Ease of installation and maintenance - Improved safety as no smartphone use or internet access is required	- Can provide very limited information about the detour plan - Information can only reach drivers nearby the traffic signs - Requires attention on the road for the traffic signs - New signs may be required if information is changed or updated

3.2. Enforcement System:

Size and weight restrictions are two enforcement criteria for Commercial Motor Vehicles (CMV). These restrictions are enforced to ensure public safety and protection of vital transportation infrastructure, for example, vehicles over 40 tons are not allowed to drive on interstate highways within the US under normal conditions. Moreover, additional constraints such as the legal load combination may apply which is a function of vehicle weight and axle spacing (2).

As stated earlier, bridge load rating and posting are essential, bridge owners must work with law enforcement to ensure that the weight restrictions are appropriately enforced. They should identify and share alternate routes and use advanced posting, so the drivers do not have to backtrack (2). Similarly, agencies along with law enforcements make sure that trucks and heavy vehicles comply with the posted load of bridges by using different enforcement methods. However, their efforts are limited by the availability of officers and resources. In recent years, different technologies were developed and added to the weight enforcement program to increase the enforcement efforts by reducing human resources (56).

3.2.1. Size Enforcement Technologies:

Starting with the first enforcement criteria, vehicle size, measuring tapes and measuring bars are used to inspect CMV's size in three dimensions against legal size limits (57). However, this traditional method has several shortcomings associated with it such as:

- An initial subjective assessment by an enforcement officer to determine if the CMV is oversized and requires inspection,
- The process of capturing the measurements is time consuming,
- Some aspects of vehicle size are difficult for the enforcement officer to determine physically or safely (e.g., the highest point of an irregular load), and
- As with any manual measurement process, the determination and documentation tasks are open to errors.

This method is being used in Slovenia, Belgium, and France despite the abovementioned shortcomings (57).

However, there are emerging technologies that address many of the shortcomings of using traditional methods such as gantry-mounted systems that are used for CMV size enforcement. These systems have different type of sensors for example infrared detectors or laser beams that are used to measure the three dimensions of a vehicle, such as the vehicle profiler system in Switzerland shown below (57).

3.2.2. Examples of Size Enforcement Applications in Europe:

Below are some examples of size enforcement applications being used in Europe:

In Switzerland, infrared detectors are used to check vehicle height as part of enforcement strategy for some of its tunnels. The detectors, which are part of a bigger system, are placed upstream of tunnels and send signals to a pole with red light that activates if the vehicle is considered over height, alerting the driver to divert away from the tunnel. Recently, the Swiss is using dimensional measuring devices that depend on laser scan technology to collect full three-dimensional profile of vehicles as shown in Figure 20. The accuracy of the system was tested for 2 years, and the Cantonal police is now using the profiler system in low speed at four locations throughout the country. It was reported that the system saved a lot of processing time, provided improved accuracy compared to manual measurement and processed more vehicles compared to manual inspection (57).

Figure 20. Swiss Vehicle Profiler System (Source: Commercial Motor Vehicle Size and Weight in Europe)

In Germany, the vehicle profiler system is used as part of the gantry mounted toll collection system. This system is used in high speed for preselection of potentially over height vehicles instead of for direct enforcement. Therefore, if the system identifies a potentially over height vehicle, then the driver is directed away from the main roadway for manual measurement activities (57).

3.2.3. Weight Enforcement Technologies:

The second enforcement criterion is vehicle weight. Static weighing system is widely used worldwide for direct weight enforcement due to the system's accuracy, portability, and simplicity compared to other weight enforcement methods (59).

Additionally, there is an emerging technology Weigh-in-Motion (WIM) that can capture detailed CMV weight for preselection of further inspection or direct weight enforcement. The International Society of Weigh-in-Motion (ISWIM) defines this technology as "the process of measuring the dynamic tire forces of a moving road vehicle – Dynamic Wheel Loads (DWL) – and estimating the Gross Vehicle Weight (GVW) and the portion of that weight carried by each wheel, axle, and axle group of a corresponding static vehicle (static wheel and axle loads)" (59).

WIM technology can be used in bridges or roads to gather detailed vehicle weight information that will replace assumptions with estimates and reduce the margin of uncertainty (59). There are many types of WIM systems, Figure 21 present an example of WIM system that is carried outside the main roadway. Vehicle weight is measured using the WIM system first and if it is above a certain threshold then the driver will be instructed to go to the static scale for further procedures, otherwise, they can use the bypass lane to go back to the main roadway if the vehicle weight is less than the threshold value (58).

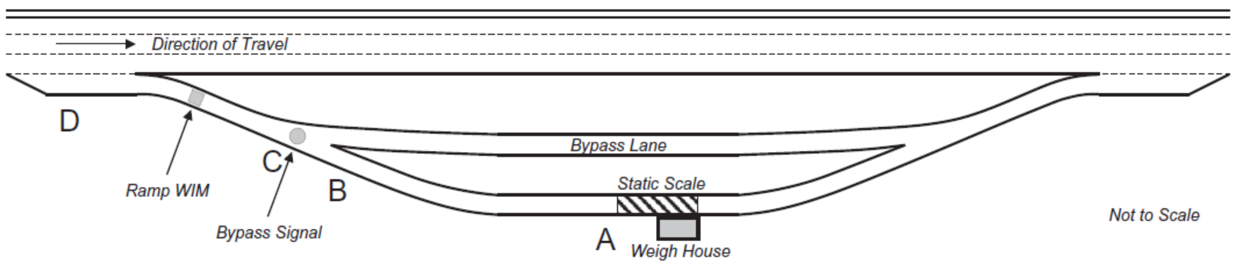


Figure 21. Concept of Weigh in Motion System (Source: Adaptive weigh-in-motion algorithms for truck weight enforcement)

3.2.4. Types of WIM Systems:

There are different types of WIM systems whose function depend on the policy needed and application. For example:

- Low speed WIM (LS-WIM): the weighing occurs in a controlled area outside the main traffic lane. To eliminate the vehicle's dynamic effects while weighing, the velocity and transverse movement of the passing vehicles are controlled (59).
- High speed WIM (HS-WIM): the weighing is carried out at traffic lanes under free-flow conditions. This system has an inaccuracy of between ±5 to ± 10 % for GVW measurements (59).
- Bridge WIM (B-WIM): This unique dynamic weighing system has the sensors located at the bottom side of a bridge's beams or deck. The sensors measure the strains due to bending of the bridge due to the passing vehicles (59).
- Dynamic On-Board WIM (OBW): Here the vehicles are equipped with the system instead of the infrastructure. The system can provide more detailed information such as measuring the GVW, axle, and wheel loads of the vehicle while it is moving. The inaccuracy is typically between ±1 and ±3 % (59).
- Stress-In-Motion (SIM): In SIM, the system can be installed in the road pavement and measures the individual multi-dimensional tire-road contact stresses (59).
- Rail WIM: While the Rail WIM system is installed in a railway track to measure trains' dynamic wheel forces with a typical measurement accuracy of ±2% of GVW (59).

However, all these systems share similar components that include:

- Weighing sensors that could be mounted in the road surface or attached to a bridge,
- Road Side Unit (RSU) that includes all electronic components, and

- Data storage devices and communication devices.

Additional sensors can be integrated to WIM systems such as:

- Temperature and deflection sensors, and
- Cameras for photos and license plate recognition in case of direct enforcement.

3.2.5. Enforcement Procedures:

Enforcement procedures is quite similar across many counties. When WIM system is not available, inspections may occur by looking for signs of overloading such as bulging tires or leaking loads. Many countries utilize mobile enforcement units and few fixed roadside weighing facilities. This method usually results in only fewer number of CMVs being inspected for overloading, however, this method does provide more flexibility to respond to industry routing patterns and more efficiently execute enforcement procedures that may include issuance of warnings or fines to violators (57).

When WIM technology is available, the system is mostly used to support enforcement through:

- Preselection of CMV for further inspection in real-time preselection,
- Planning the time and location of enforcement activities, and
- Collecting data and directing CMV companies' advisory notices of noncompliance.

3.2.6. Examples of Weight Enforcement in Europe:

Below are some examples of weight enforcement applications being used in Europe:

Slovenia is considered one of the first countries to adopt B-WIM technology. The system which is attached to bridges or culverts uses strain transducers to capture bridge deflection measurements under moving loads. Axle measurements can be captured through traditional portable or permanent axle sensors or through Nothing-on-the-Road (NOR) / Free-of-Axle Detector (FAD) systems, which require no axle sensors on the road surface (57) as shown in Figure 22.

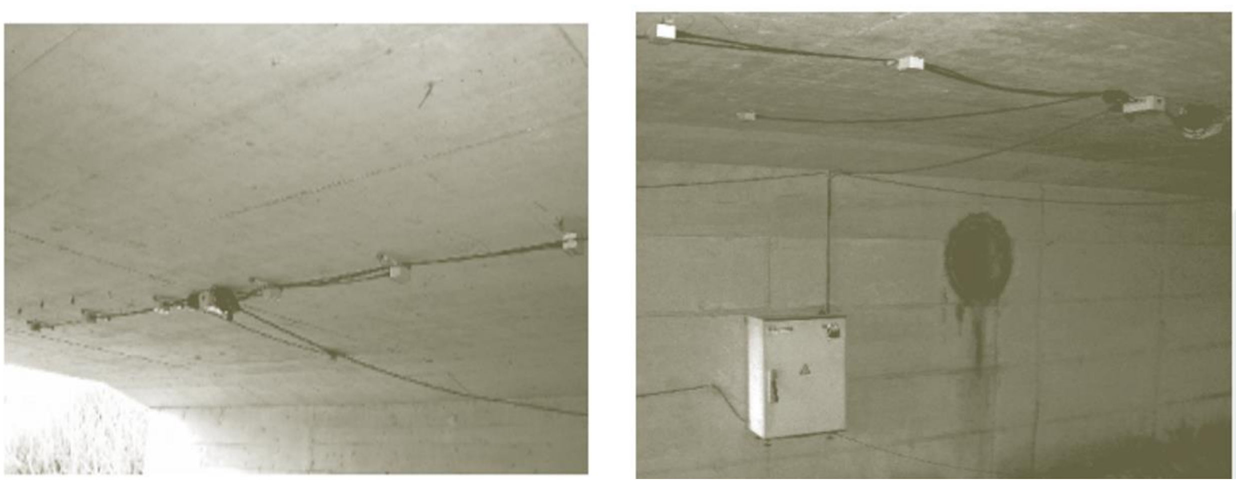


Figure 22. Slovenia B-WIM Technology (Source: Commercial Motor Vehicle Size and Weight in Europe)

In the early 1990s, Slovenia was working on next generation prototypes of B-WIM technologies that have better accuracy and more applicability. In 1999, the improved product (called SiWIM) was commercialized through a partnership between the Slovenian National Building and Civil Engineering Institute (ZAG) and a private manufacturing company called Cestel. Nowadays, SiWIM is available in over 60 locations in Slovenia, Sweden, France, the Netherlands, Croatia, and India among other countries (57).

While in Switzerland, Kistler, a Swiss company built a WIM system that works on quartz-based piezo sensor. The advantages of this system included:

- Does not get affected due change in temperature,
- Can be statically calibrated on site,
- Does not get affected by horizontal stresses induced in the road surface,
- Able to function as a true pressure sensor.

After successful test period, the system was implemented in many counties in Europe as well as in the US. However, the first generation of piezoquartz sensors had durability issues which required regular replacement between 1995 and 2005. Although the company stated that the newer sensor generations did resolve the durability issue (57).

All new WIM sites in Swiss use piezoquartz technology due to their accuracy and increased reliability. However, the Cantonal Police use the WIM systems for preselection of CMV only while they use the traditional static scales for CMV weight enforcement (57).

In the early 1990s, the German Federal Highway Research Institute (BASt) in Germany was working on performance of various WIM systems that included different types of sensors such as Golden River capacitance strip sensor, an ECM piezoelectric sensor, and a PAT bending plate system. Concurrently, another project titled Top Trial project that involved four participating countries, namely, Germany, the Netherlands, Portugal, and Switzerland, the project objective was to increase the precision of weight measurement of truck loads to cover future regulations and to propose future standards as basis for enforcement (57). Since these projects yielded good results, Germany started implementing bending plate WIM systems. In 1999, more than 15 WIM systems installed. In 2000, the Swiss company, Kistler, was commissioned by Germany to install 13 WIM stations using its piezoquartz sensors. Currently, there are over 40 WIM systems in Germany some of which use bending plate and the other use piezoquartz technology, the WIM system is being used for preselection for weight enforcement as well as for collecting statistical data (57). According to the BASt's research, all WIM systems required periodic calibration to ensure the accuracy and efficiency of the systems. It was recommended that calibrations should be conducted at least once every six months by observing the axle load distribution at each WIM site by using two trucks of known weight, one that is half loaded and the other that is fully loaded, performing at least 15 runs using each truck (57).

In 1997, in the Netherlands, there were plans to install between 40 – 60 WIM throughout the country starting with 5 WIM systems in that same year. However, the Ministry of Transport reported that the first 6 WIM systems were installed in 2006 with additional 2 WIM sites being under construction. The Dutch used Kistler's WIM technology with piezoquartz, but they did face some durability issues related to its roads' porous asphalt design (57). Since the deployment of

WIM systems, the Dutch made significant improvements to their systems that they use them for automated enforcement of overloading. They achieved the required accuracy by using high-speed, multiple-sensor WIM system.

Belgium also participated in projects that studied WIM systems, the Belgian Road Research Center (BRRC) performed tests such as Continental Motorway Test (CMT) in France and Cold Environmental Test (CET) in Sweden. The CMT is part of European test program for WIM that conducted the analysis on slow lanes of busy motorways while the CET was to analyze the performance and accuracy of WIM systems under cold weather conditions. The WIM system in Belgium is used mostly to collect statistical data for planning purposes rather than for preselection of potentially overloaded vehicles. Belgium has a variety of WIM systems such as static WIM, low speed WIM and high-speed WIM. Belgium reported facing many challenges with their WIM systems that included: frequent maintenance of the WIM stations, periodic calibration, progressive drift of some stations due to the heavy reliance on automatic calibration, and a rutting condition forced the automatic calibration of one of the stations to stop working. These challenges were thought to occur due to the site conditions of the WIM system locations (57).

France is one of the leading countries that heavily invested in studying WIM systems and its applications. Since the late 1970s, France participated in many projects and field studies that aimed to improve the accuracy of WIM systems such as COST 323 and WAVE. For example, France conducted a three-day experiment conducted in Trappes in 1996 that consisted of four portable piezoceramic WIM system arranged in a Multiple Sensor WIM formation (MS WIM). The experiment was conducted on a heavy traffic road for 116 runs with two preweighed test vehicles. In the upstream, 92 vehicles were randomly stopped and statically weighted. THE MS WIM system collected the axle loads and gross weights of almost 4,000 vehicles were recorded in the traffic stream. The data collected from the MS WIM was compared to the statically collected data for accuracy. Additionally, A two phased study was conducted in L'Obrion from March 1997 to October 1998. The goal of this CMT test was to assess the accuracy of 6 different WIM systems developed by four European manufacturers. One of the systems used capacitive mat while the other five systems used piezoceramic bars. The WIM systems were installed on the slowest lane of heavy traffic roadway, the test lasted 17 months during which 700 observations from the systems were recorded and compared against the results of static weighing of the same sample vehicles. In the second phase, the same WIM systems were used after manufacturers made some system improvements and adding additional components to their systems (57).

Furthermore, France also studied the benefits of using of fiber-optic strip sensors in WIM systems, The test that was conducted at two different locations and concluded that there were a lot of advantages of using fiber-optic strip sensors such as: good accuracy, is not impacted by temperature change (during hot or cold climates), capable to work with high speed and static systems, immune against electromagnetic, easy to install, data is processed in very short time among other advantages. France also investigated two prototypes of VIDEO WIM systems to study the possibility of fully automating the enforcement activities. The objectives were to: preselect overloaded vehicles from the traffic stream for enforcement activities in real time, prevent overloading behavior by targeting companies contacts of repeated overloading violations, and to forecast the locations where overloading may occur the most to support scheduling of mobile enforcement patrols. Two different systems were used, at two separate locations, at the beginning, both systems performed poorly and did not reach the required accuracy not due to the inefficiency of the systems but because of poor road conditions at both sites. Still, 81% of the identified vehicles were statically weighted and found to be overloaded. Based on the successful testing of VIDEO WIM, France planned to install between 10 to 40 similar systems all over the country. France tested the Slovenian bridge WIM system (SiWIM) on different bridge structures as shown in Figure 23. The SiWIM was known to work very well with short-span integral concrete bridge. However, France wanted to test the system on orthotropic steel bridge structures since their behavior is independent of their span lengths (57).

Figure 23. SiWIM Testing in France (Source: Commercial Motor Vehicle Size and Weight in Europe)

Nowadays, France has around 170 WIM systems that collect weight data for planning support, these systems depend on automatic self-calibration and comparative review of static weight data that were obtained during enforcement activities. Therefore, they don’t require annual manual calibration for improved accuracy (57).

3.2.7. Enforcement Challenges:

WIM technologies provide a lot of promising advantages that can better increase the effectiveness of bridge load posting enforcement systems, however, WIM systems also come with some obstacles such as:

- Cost: Since WIM systems vary in cost depending on the type of WIM system as well as technology of the sensors being used. For example, a WIM system that uses piezoelectric sensor for traffic monitoring is considered relatively low cost. However, many states do use quartz piezo WIM systems as they provide many advantages during enforcement activities. Different states reported the cost of piezoelectric WIM per lane to be $16,000 while the cost of quartz piezo WIM is about $29,000 per lane and the cost of bending plate WIM and single load cell system were approximately $40,000 and $87,500 per lane, respectively. Overall, the construction cost of a typical weigh station can reach $12 million. While the cost of constructing Virtual Weigh Stations (VWS) or deployment of mobile screening is considered way cheaper when compared to building a new WIM station. Therefore, most states rely on the latter two than building a new weigh station (56).

- Manpower: WIM systems require a lot of specialists to operate and observe the system such as: size, weight, and safety specialists as well as specialists that interact with vehicles that require static weighing. Additionally, enforcement personnel are also required to issue citations for violating vehicles (56).

- Interagency cooperation: There are a lot of benefits when several technologies are combined and used together instead of used independently. However, there are some technological and institutional challenges when combing different technologies. For example, a weigh station that supports digital imaging, Automatic Vehicle Identification (AVI), access to commercial vehicle data and advanced screening algorithm requires integrated architecture and the cooperation of the state's transportation department, law enforcement agency and motor vehicle agency. However, the lack of such interagency cooperation will considerably reduce the system effectiveness (56).

- Data issues: There are concerns that collected data should do not be kept for an extended period of time, they should be collected for statistical planning and enforcement purposes only and they should be safely secured without unique identifiers (56).
- Technology performance: There are performance limitations to due technologies such as AVI. License plates are not standardized throughout the US and are not optimized for automated reading, therefore, Optical Character Recognition (OCR) or License Plate Reader (LPR) will not correctly identify 100% of tested vehicles (56).
- Funding: Lack of funding is a major obstacle that many states face. The Federal Commercial Vehicle Information Systems and Networks (CVISN) is the main funding source that many states depend on for support of virtual WIM stations deployment. Some states have reached the maximum limit and are not eligible to receive additional funding to support their WIM system deployment (56).
- Lack of standards/architecture: Architecture for new roadside operations such as virtual weigh stations are yet to be established. The lack of such architecture makes not difficult to realize consistency in the designing, deployment, communication systems, software among other aspects in different jurisdictions (56).

3.3. Review of Existing ITS Condition in Louisiana:

In this section, we are presenting a summary of the existing Intelligent Transportation Systems (ITS) technologies that are being used in the State of Louisiana (LA). The information provided in this section were obtained from LADOTD, presentation titled: Intelligent Transportation Systems in Louisiana (60).

3.3.1. Traffic Management Center (TMC):

Traffic Management Centers are central hubs where ITS applications and equipment are integrated to support real time traffic operation and management on highways and arterials. There are five existing TMCs scattered throughout the State of Louisiana as follows:

- Two TMCs in Baton Rouge, one is statewide and the other one is regional,
- One TMC in New Orleans,
- One TMC in Houma, and
- One TMC in Shrevport.

Additionally, there are four TMCs planned for future:

- One TMC in Alexandria,
- One TMC in Monroe,
- One TMC in North Shore, and

- One TMC in Lake Charles.

The locations of existing and planned TMCs are shown Figure 24 in below.

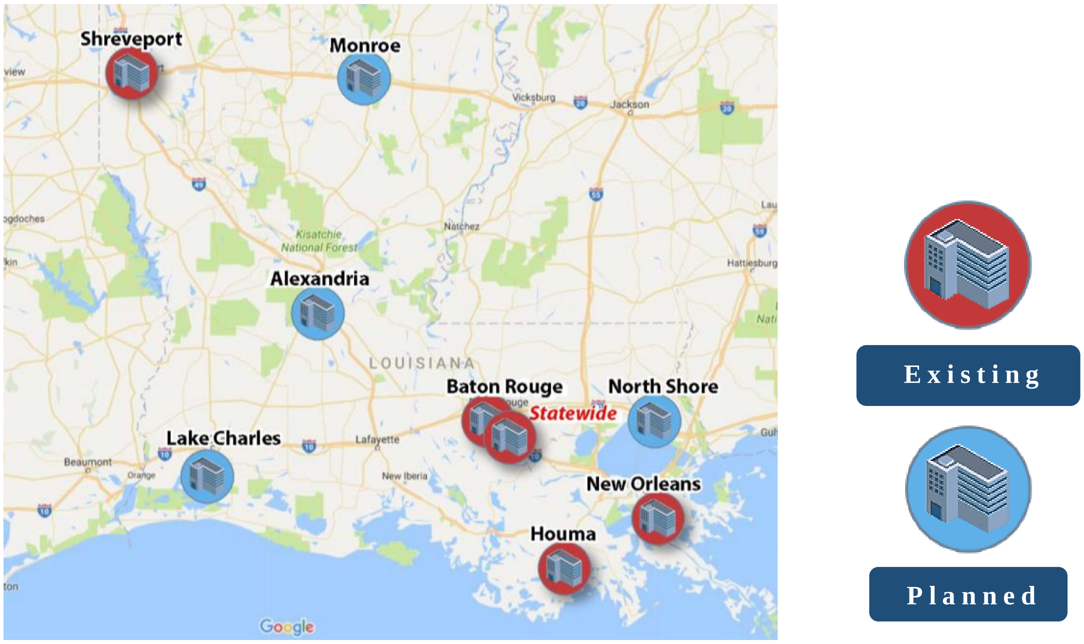


Figure 24. LADOTD Existing and Future TMC Locations (Source: Intelligent Transportation Systems in Louisiana Presentation)

The primary functions of these TMCs are to:

- Operate traffic control devices,
- Communicate with stakeholders and first responder agencies,
- Monitor the transportation network, and
- Push traveler information to the public.

When an incident occurs, information is obtained via Closed-Circuit Television (CCTV), agency reports, motorist reporting, and congestion mapping. Then the information is analyzed and verified using CCTV and Advanced Traffic Management System (ATMS) software. Finally, the public are notified of the incident using various traveler information methods such as Dynamic Message Signs (DMS), 511 system and Twitter feed. This process is called the incident management process which is represented visually in Figure 25 (60).

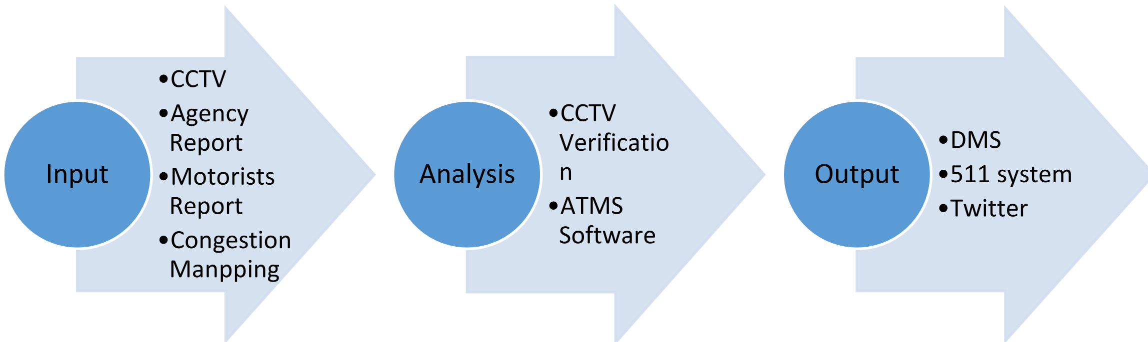


Figure 25. Incident Management Process (Source: Intelligent Transportation Systems in Louisiana Presentation)

3.3.2. Motorist Assistance Patrol (MAP):

Motorist Assistance Patrols (MAP) are specially equipped patrols that provide many free services to motorists for example:

- A gallon of fuel,
- Changing a flat tire,
- Towing broken-down vehicles.
- Jump starting stalled vehicles, and
- Filling radiators of vehicles with water,

The MAP program which is currently sponsored by State Farm started in Louisiana in the mid – late 1990's. The program aims to:

- Improve safety by managing the traffic during incidents,
- Ensure smooth flow of traffic by towing vehicles obstructing the traffic outside the main carriageway,
- During special events, provide support to reduce the impact on traffic, and
- Increase traffic safety by providing support for detours and road closures.

The location of current deployment and future plans of MAP service are shown in Figure 26. Currently, MAP vehicles are available in:

- Baton Rouge,
- Lake Charles,
- New Orleans, and
- Shreveport.

Moreover, there are plans for expansion of MAP services in the future in:

- Alexandrea,
- Monroe, and
- North Shore.

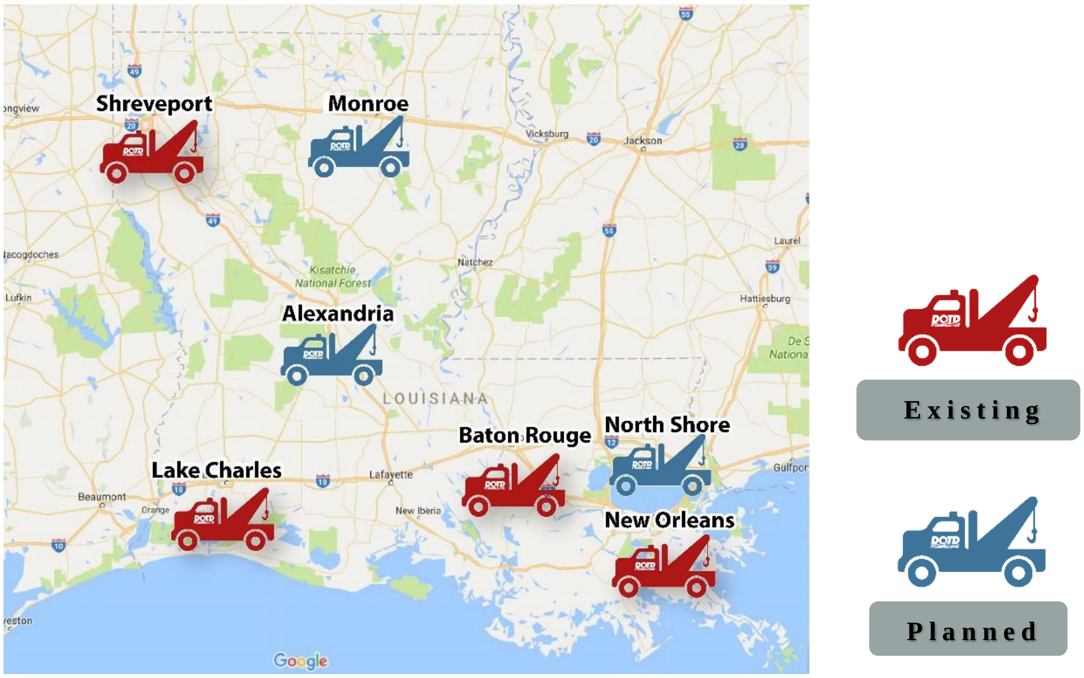


Figure 26. Existing and Future MAP Service Location (Source: Intelligent Transportation Systems in Louisiana Presentation)

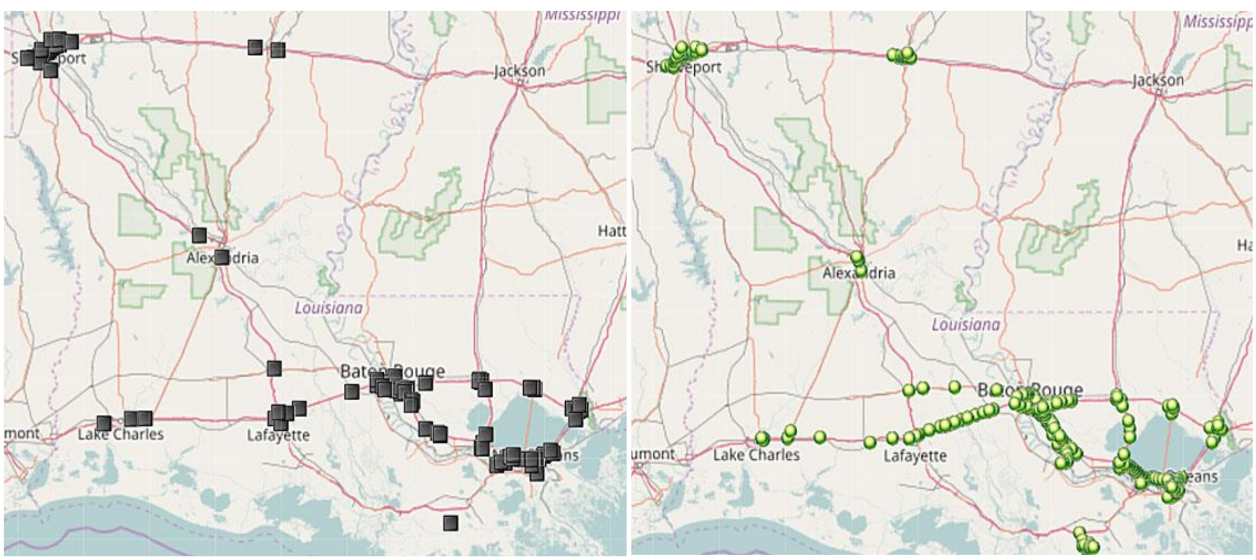
3.3.3. ITS Devices:

LADOTD utilizes many ITS devices to improve the driving experience efficiency on its infrastructure. Existing ITS devices in Louisiana include:

- 106 DMS scattered along the interstates throughout the state such that:
  - 1 DMS at Houma
  - 4 DMSs at Alexandria
  - 4 DMSs at Monroe
  - 7 DMSs at Lafayette
  - 7 DMSs at Lake Charles
  - 13 DMSs at North Shore
  - 18 DMSs at Shreveport
  - 25 DMSs at Baton Rouge
  - 27 DMSs at New Orleans

- 455 CCTV Cameras 75% of which have Pan, Tilt, and Zoom (PTZ) functions while the remaining 25% are fixed cameras. They are also deployed around the same locations of the DMSs as follows:
    - 13 CCTVs at Houma
    - 20 CCTVs at Alexandria
    - 24 CCTVs at Monroe
    - 31 CCTVs at Lafayette
    - 31 CCTVs at Shreveport
    - 34 CCTVs at Lake Charles
    - 43 CCTVs at North Shore
    - 98 CCTVs at New Orleans
    - 161 CCTVs at Baton Rouge
- LADOTD utilizes Bluetooth readers in Baton Rouge to calculate travel time.
- LADOTD operates and maintains 2,745 traffic signals in Louisiana, 18% of which are centralized. Currently, LADOTD is working on connecting the remaining signals to the TMCs.

The majority of DMSs and CCTVs are deployed in or around both Baton Rouge and New Orleans as can be seen from Figure 27 below (60).



DMS Locations CCTV Locations

Figure 27. DMS and CCTV Locations in Louisiana (Source: Intelligent Transportation Systems in Louisiana Presentation)

3.3.4. ITS Technologies:

LADOTD takes advantage of many technologies to disseminate important traveler information that may assist drivers to plan their journeys in advance (pre-trip) or to adjust their route while on the road depending on the traffic conditions (en route) as presented in Figure 28 – Figure 30 (61–63).

- LADOTD website at http://www.dotd.la.gov/Pages/default.aspx,
- 511 phone service,
- Louisiana 511 smartphone application that is available for both Android and iPhone users, and
- Twitter Feed.

Figure 28. Information Dissemination for Travelers (Source: LADOTD Website)

Figure 29. Information Dissemination for Travelers (Source: LADOTD Twitter Account)

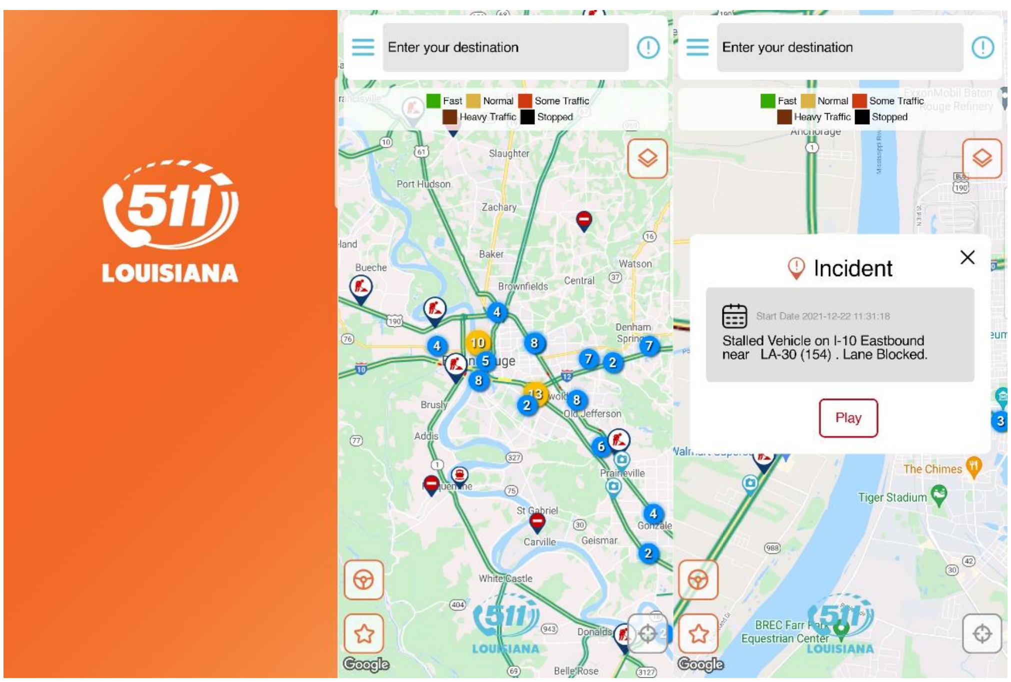


Figure 30. Information Dissemination for Travelers (Source: LADOTD 511 Smartphone Application)

3.3.5. Commercial Vehicle Operations (CVO):

LADOTD manages the transportation of freights within the State according to the Louisiana Freight Mobility Plan published in 2015 which also meets the federal requirements for freight transportation. Additionally, LADOTD issued the 1998 Commercial Vehicle Operation (CVO) plan which needs to be updated to align with the recently published Freight Mobility Plan (60).

There are 6 permanent Weigh in Motion (WIM) stations and 3 temporary stations to enforce the weight restrictions of commercial vehicles in Louisiana. Some of these stations offer PrePass, a service that allows commercial vehicles to bypass WIM stations. Vehicles equipped with PrePass are prescreened electronically as they approach WIM stations. If the system determines that vehicles are within the safety standards, they can continue their journey without ever stopping at the WIM stations thus saving drivers valuable time and fuel (60).

3.3.6. Communication Network:

ITS depend on communication network to ensure efficient and smooth traffic operation. Most of the services and programs discussed above require at least one type of communication method between field devices, equipment, data processing units and terminals. LADOTD rely on integrated communication systems that consist of:

- Wired networks,
- Wireless networks,
- Transmission systems,
- Relay stations, and
- Data terminal equipment.

LADOTD owns approximately 250 miles of fiber optics while 400 miles are permit fiber optics, as shown in Figure 31 (60).

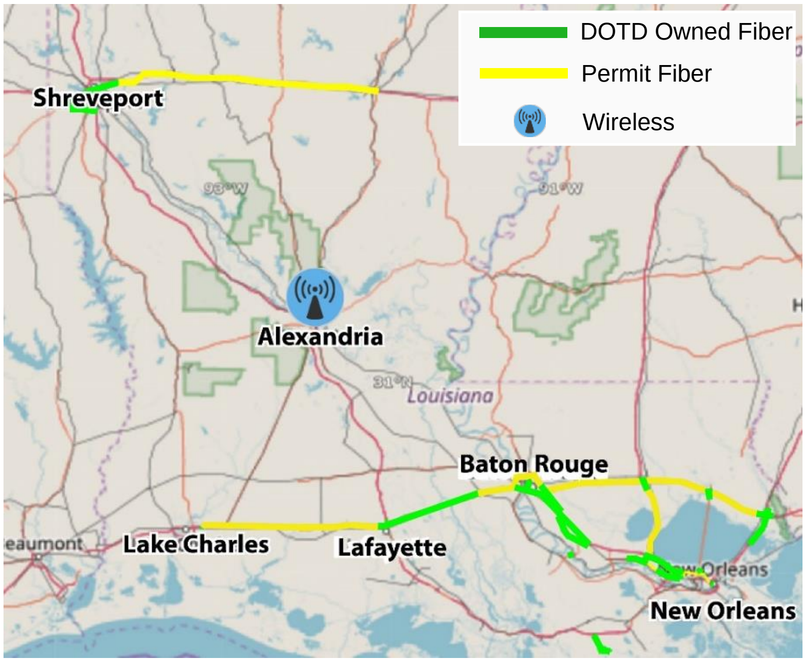


Figure 31. LADOTD Wired and Wireless Communication Network (Source: Intelligent Transportation Systems in Louisiana Presentation)

3.3.7. Tolling Operation:

LADOTD has one tolling operation on the LA-1 bridge on the LA1 Expressway at Leeville. This tolling system has an annual budget of $3 million and generates about $6.4 million in revenues. Motorists can also use their GeauxPass to electronically pay the tolling fee when passing through the system. Figure 32 presents the location of the tolling system (60).

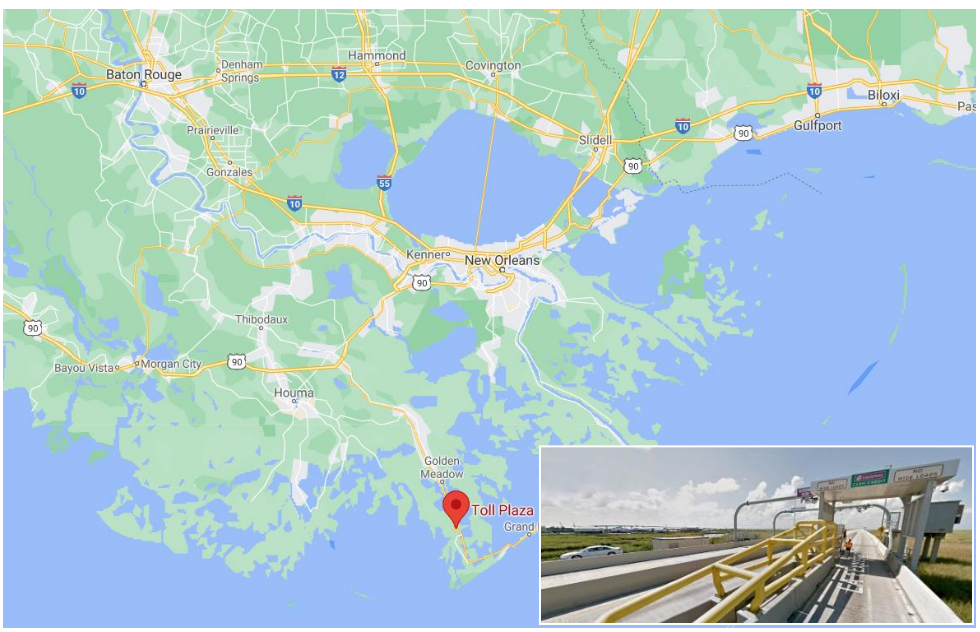


Figure 32. Location of the Tolling System on LA-1 Bridge, Leeville LA (Source: Intelligent Transportation Systems in Louisiana Presentation)

3.3.8. Advanced Transportation Management System (ATMS):

LADOTD is currently using Parsons iNET™ ATMS as their platform for all traffic management activities statewide. iNET is integrated with all the ITS devices within each TMC region. For instance, some of the modules include:

- Traffic cameras (CCTV),
- MAP Automated Vehicle Locator (AVL),
- Ramp Metering System (RMS),
- Vehicle Detection System (VDS).

3.3.9. Connected and Automated Vehicle (CAV) Readiness:

The timetable of LA Connected and Automated Vehicle (CAV) laws is as follows:

- Act 318 of 2016 – HB1143 enacted August 1, 2016 (defines "Autonomous Technology" as well as other related terms)
- Act 310 of 2018 – HB308 enacted January 1, 2019 (defines "Platooning" and provides for the legal operation of platoons)
- Act 232 of 2019 – HB455 enacted August 1,2019 (permit autonomous vehicles to transport passengers or property if they are deemed able to follow state vehicle and traffic laws, meet federal vehicle safety standards and achieve "a minimal risk condition if an (operational) failure occurs.")

In December 2020, LADOTD completed its policy and permits regarding CAV in accordance with LA Automated Commercial Motor Vehicle Law. LADOTD is currently working on its CAV Strategic Plan that is expected to be completed soon (60).

LADOTD have a CAV technology team that consist of 30 multidisciplinary members in 25 sections and districts, their mission is to:

- Develop and maintain a working knowledge of advancements in CAV technology,
- Monitor and share industry activity,
- Determine state and local transportation agency roles in supporting CAV technology,
- Formulate LADOTD policy,
- Advise local governments of what we believe their roles and responsibilities are, and
- Identify CAV applications for use within LADOTD.

4. METHODOLOGY

This section summarizes the overall methodology that was carried out in this project. It provides details of each task that was completed to achieve the project objective. Figure 33 illustrates the overall approach and tasks as well

4.1. Task 1 – Stakeholders Engagement

This task started by conducting a kick-off meeting with Transportation Consortium of South-Central States (Tran-SET) and project's committee to introduce the project objectives, initial research plan and get their feedback. The meeting took place in October 2020.

In addition, this task included several engagement activities. Stakeholders such as LADOTD played a key role in providing general feedback through the project's phases as well as informing the research team of current LADOTD processes, procedures, and ITS infrastructure.

4.2. Task 2 – Literature Review of Best Practices related to notification systems that effectively communicate bridge load postings to dispatchers and drivers

During this task, an in-depth literature review was conducted (as shown in Section 3 of this report) to identify the most relevant recent studies/best practices to the scope of the proposed research. Specifically, this phase of the project included the development of two sub-tasks:

4.2.1. Task 2-a: Review and identify best practices related to notification methods

This sub-task provided an outline of the related ITS-based notification systems utilized by local and state DOT agencies across the U.S and/or overseas for communicating load postings (or methods that can be directly utilized for this purpose). The thorough review included summarizing the state-of-the-practice as well as methods that may be adopted in the near future.

4.2.2. Task 2-b: Review and identify best practices related to enforcement methods

This sub-task developed an outline of the related state-of-the-art enforcements methods/systems utilized by local and state DOT agencies across the U.S and/or overseas for successfully administering load postings (or methods that can be utilized for this purpose). Such methods/systems included weigh-in-motion devices, various alarm systems, and various notification systems (to law enforcement).

To better achieve this task, a national survey targeting State DOTs and various law enforcement agency including the Department of Public Safety (DPS), State Highway Police (SHP) and Department of Motor Vehicles (DMV) in the 50 States within the United States was conducted. The survey consisted of two parts, the notification methods section and the enforcement methods section of bridge load posting. It was designed to identify the current technologies used by States to notify the public of bridge load postings as well as the current technologies to enforce these load postings. Also, the survey aimed to collect the current limitations faced by the States while using these technologies to provide recommendations based on identified best practices.

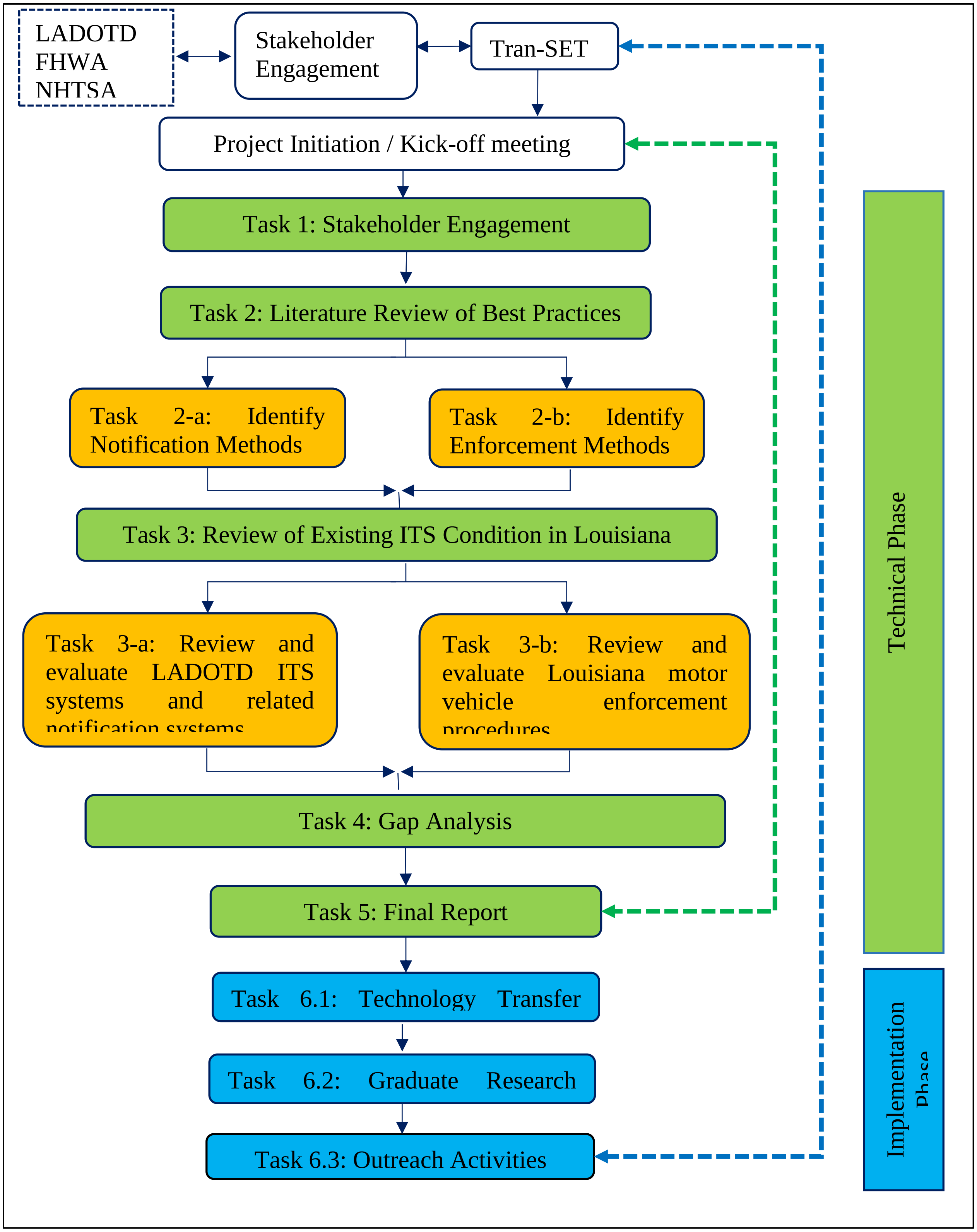


Figure 33. Overall Research Approach and Tasks

4.3. Task 3 – Review of Existing Conditions related to ITS and notification systems in Louisiana

This phase of the project included performing two subtasks:

4.3.1. Task 3-a: Review and evaluate LADOTD ITS systems and related notifications systems

During this task, the research team strived to gain all available information regarding existing ITS and notification systems in Louisiana (e.g., the Louisiana 511 Traveler system), and other capabilities that may be leveraged for a load posting notification and enforcement system.

4.3.2. Task 3-b: Review and evaluate Louisiana motor vehicle enforcement procedures

During this task, the research team gained all available information regarding Louisiana motor vehicle enforcement procedures and capabilities (which may be improved to enforce load postings). In addition, the review included collecting information related to the current load postings in Louisiana: their location, jurisdictional boundaries and procedures, and available system resources (i.e., what notification and enforcement capabilities may be reasonably expected at these sites).

To better achieve these two sub-tasks, a survey targeted LADOTD staff and other local and State officials in Louisiana was conducted to collect the required information.

4.4. Task 4 – Gap Analysis

Considering the results of Tasks 2 and 4, a gap analysis was conducted to identify the gaps the status of existing ITS and notifications systems in Louisiana and the state-of-the-art systems available in other states across the US or overseas. This task was divided into subtasks as follow:

4.4.1. Task 4-a: Identify gaps between best practices and existing conditions in Louisiana

In Task 4-1, a gap analysis between the best practices and existing conditions of ITS and notifications systems in Louisiana was conducted. The research team provided recommendations regarding several plausible notification systems and corresponding enforcement methods.

4.4.2. Task 4-b: Present Recommendations

The outcomes from this task included providing some recommendations on how the existing ITS and notification systems/procedures in Louisiana can be improved to achieve the project objectives.

4.5. Task 5 – Final Report

In this task, the research team consolidated the information and results obtained from all the previous tasks (tasks 1-4) and prepared a final report documenting the entire project and incorporating all other specified deliverable products of the research.

5. ANALYSIS AND FINDINGS

To review and evaluate the existing notifications and enforcements systems as well as procedures for bridge loads in the US, a national online survey was designed and conducted targeting State DOT professionals as well as State employees working in various law enforcement agencies such as Department of Public Safety (DPS), State Highway Police (SHP) and Department of Motor Vehicles (DMV) in the United States. The survey aimed to gain more insights about the current notification and enforcement systems used in each state to administer load rating, posting, and enforcement at bridges. The survey also intended to highlight the challenges and limitations that stand as obstacles against effectively posting and enforcing bridge loads in the United States.

The survey consisted of two parts, part one included 11 questions discussing the current and best practices notification systems/procedures to communicate and administer bridge load postings in the US while the second part included 9 questions discussing the current and best practices enforcement systems/procedures to communicate and administer bridge load postings in the US. A total of 38 states (DOT professionals) responded to Part 1 of the survey: notification systems/procedures (response rate of approximately 76%) while 20 states (DPS, SHP and DMV professionals) responded to Part 2 of the survey: enforcement systems/procedures (response rate of about 40%). It is worth mentioning that the survey was reviewed and approved by the Institutional Research Board (IRB) at LSU. A copy of the survey questions can be found at Appendix A. We would like to thank DOT professionals and state employees that responded to the survey for their time and efforts as well as their valuable input helped us better understand the current notification and enforcement systems used to communicate to motorists – especially truck drivers – bridge load postings as well as enforcing them.

5.1. Analysis of Section 1: Notification Systems/Procedures to Communicate and Administer Bridge Load Postings

Starting with the notification section of the survey, participants were asked to report the current specifications used for load rating and posting of bridges at their states. As shown in Figure 34, the findings indicated that about two thirds (66%) of the states participating in this study are using AASHTO Manual for Bridge Evaluation (MBE), 2nd Edition as their specification for load rating and posting of bridges while 24% are using the AASHTO MBE, 3rd Edition, and about 11% are using other specifications (e.g., Colorado Bridge Rating Manual, Florida Department of Transportation (FDOT) Bridge Load Rating Manual, Idaho Manual for Bridge Evaluation, Kansas DOT Design Manual, South Carolina DOT Load Rating Guidance Document, West Virginia Bridge Load Rating Manual). It is worth mentioning that the result of this question is consistent with prior studies (e.g., Bowman and Chou, 2014).

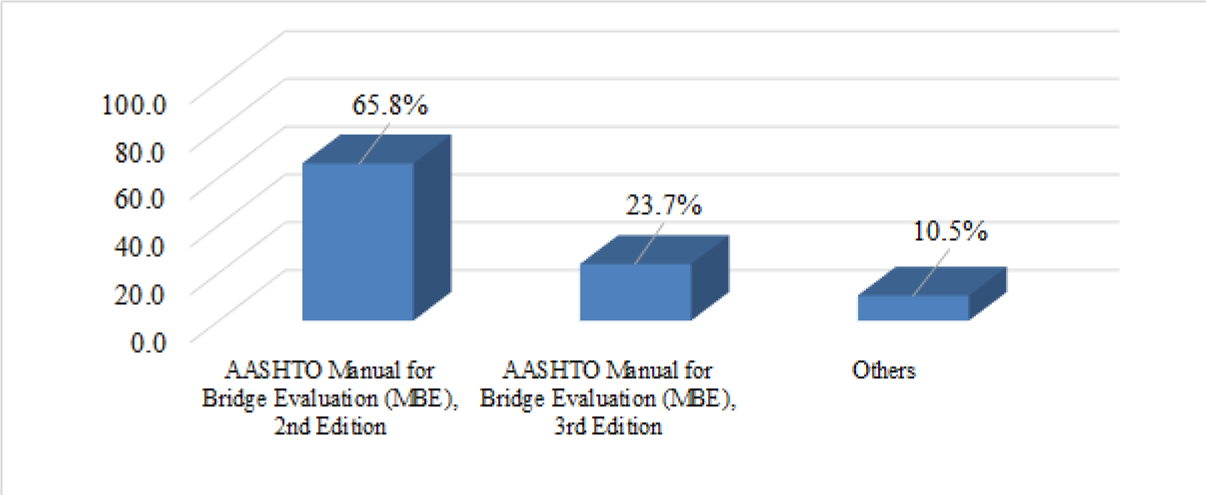


Figure 34. Current Specification Used for Load Rating and Posting of Bridges in the US

The second question was about the current method used by each state for load rating and posting of bridges (Allowable Stress Rating "ASR", Load Factor Rating "LFR" or Load and Resistance Factor Rating "LRFR"). As shown in

Table **3. Current Method Used for Load Rating and Posting of Bridges in the US**

S.N.	Load Rating Method and Posting Method	Percentage
1.	ASR, LFR, and LRFR	36.8%
2.	LFR and LRFR	13.2%
3.	LRFR	23.7%
4.	LFR	26.3%

The third question discussed whether the State DOT have any software that is currently used for Load Rating. As shown in Figure 35, the results indicated that about 92% of respondents are using at least one software for Load Rating while 8% do not use any load rating software. The commonly used software was AASHTOW are BrR (used alone by 34% of participants and used along other software by 21% of respondents). However, about 37% of participants reported that they use other software such as Bentley LARS and in-house developed software.

, it was found that none of the states are using ASR method alone. However, the results showed that about 37% of respondents are using all three methods (ASR, LFR and LRFR), 26% are using LFR, 24% are using LRFR and 13% are using LFR and LRFR.

Table 3. Current Method Used for Load Rating and Posting of Bridges in the US

S.N.	Load Rating Method and Posting Method	Percentage
1.	ASR, LFR, and LRFR	36.8%
2.	LFR and LRFR	13.2%
3.	LRFR	23.7%
4.	LFR	26.3%

The third question discussed whether the State DOT have any software that is currently used for Load Rating. As shown in Figure 35, the results indicated that about 92% of respondents are using at least one software for Load Rating while 8% do not use any load rating software. The commonly used software was AASHTOW are BrR (used alone by 34% of participants and used along other software by 21% of respondents). However, about 37% of participants reported that they use other software such as Bentley LARS and in-house developed software.

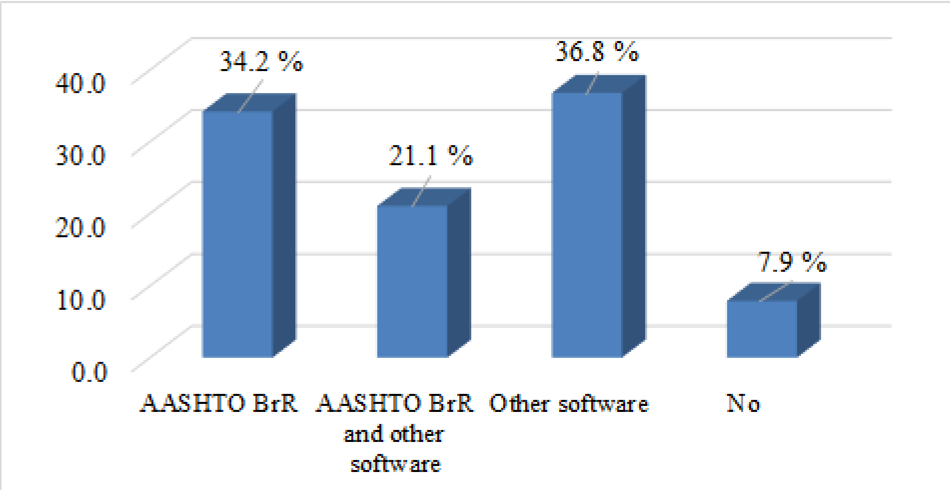


Figure 35. Software used for Bridge Load Rating

Survey participants were then asked about the specification used for load posting signage at their states. The results revealed that approximately 79% of the State DOTs are using Manual on Uniform Traffic Control Devices (MUTCD) as their specification for load posting signage at bridges, while 22% are using a combination of both MUTCD and other State own manuals as shown in Table 4.

Table 4. Specifications for Load Posting Signage in USA

S.N.	Specification Used for Load Posting Signages	Percentage
1.	MUTCD	78.9%
2.	MUTCD supplemented by State DOT Specific Guidance	21.1%

Next, the State DOTs were asked about the frequency of administering load rating, in which 87% responded that they administer bridge load rating analysis when the bridge's structural condition changes or as needed. On the other hand, only 5% and 8% of participating states indicated that they perform load rating analysis once every 12 months or every 12-24 months, respectively as shown in Figure 36.

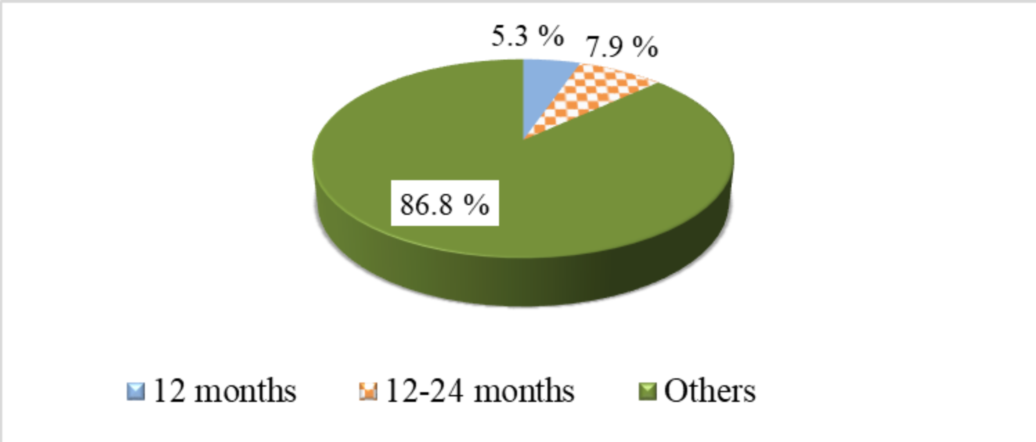


Figure 36. Load Rating Analysis Frequency

The following question was regarding the current notification methods used by each State. It was found that about 24% of the states are using bridge load posting signs while 76% are using bridge load posting signs along with other methods as shown in Table 5. The other methods included

- Online statewide map/Website indicating current bridge posting status as reported by Missouri, Montana, Nebraska, North Carolina, South Carolina, North Dakota, South Dakota, Texas, Virginia, Washington,
- Online Automated Routing and Permitting System as reported by North Dakota,
- Booklet, as stated by South Dakota.

Table 5. Bridge Load Notification Methods in USA

S.N.	Bridge Load Notification Methods	Percentage
1.	Bridge Load Posting Signs	23.7%
2.	Bridge Load Posting Signs and Other Methods	76.3%

Survey participants were then asked to report if there any mobile app that is being used to communicate with drivers about the bridge load postings at their states. As shown in Figure 37, only 8% of participating DOT's have a mobile app (e.g., IDrive Arkansas) to communicate with drivers about the bridge load postings.

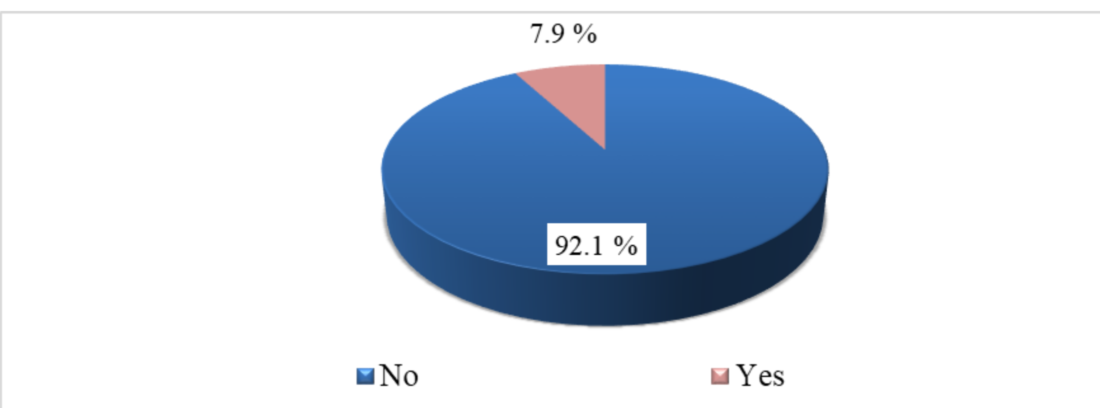


Figure 37. Availability of Mobile Apps for Bridge Load Notification

Then, survey participants were asked about the main limitations of the current notification procedures of load posting signage at their states. As shown in Figure 38, the results revealed that the limitations are as follows:

- Limitations due to driver related factors such as ignoring/failing to comply with posted signages and misinterpretation of signages, reported by approximately 26% of the State DOTs.
- Limitations due to signage such as signage proximity to the bridge which gives awareness at a short notice, improper maintenance of damaged or stolen signs, the use of small font to add a lot of information that confuses drivers. This limitation was reported by over 21% of the State DOTs participating in this study.
- Limitations due to technology such as the lack of unified online platform or a user-friendly smartphone application to notify truck drivers of load posting, reported by about 12% of the survey participants
- Resources or administration related limitations such as lengthy procedures and lack of open communication within the department, reported by nearly 10% of the survey participants.
- Awareness related limitations in terms of being uninformed of the availability of online tools for bridge load posting as well as the unit conversions; in the trucking industry the standard unit used for weight measuring is thousands of pounds while the MUTCD standard signs show the units in tons. This limitation was reported by about 7% of the survey participants.

Finally, it is worth mention that about 24% of participating State DOTs indicated that there are no limitations with their current notification procedures.

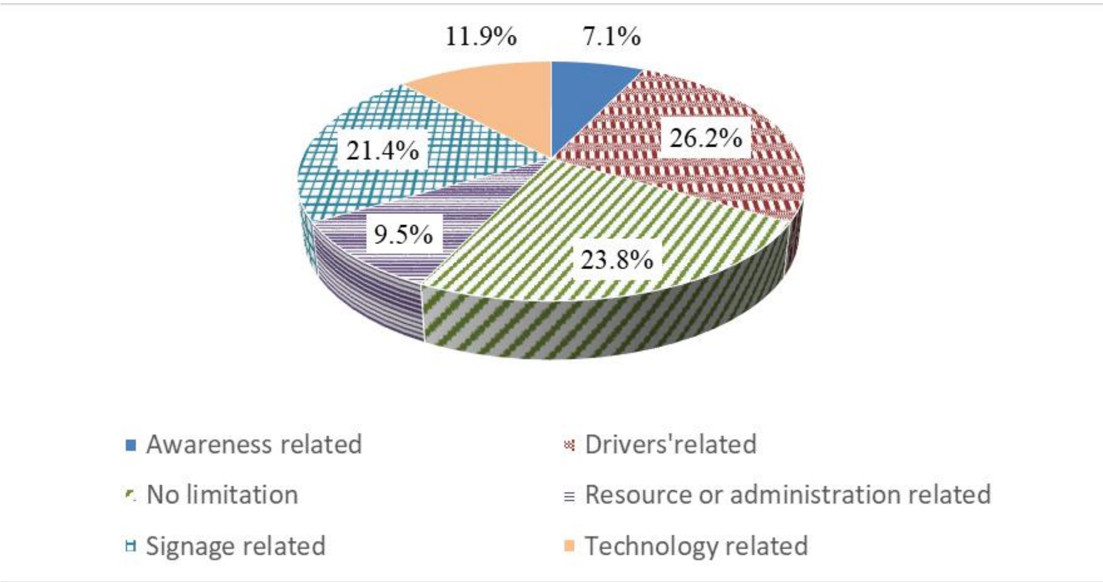


Figure 38. Main Limitations of Current Notification Procedures

Following on the previous question, the survey participants were asked to list some important modifications that can improve their current notification systems at their states. As shown in Table 6, about 34% of the survey participants indicated that the development of a website or mobile application could significantly improve the notification system in their state. Whereas about 15% of the survey participants mentioned that driver education is vital to improve the notification system. They stated that truck drivers need to be able to better understand and interpret posted load signs. Moreover, about 7% of the survey participants claimed that advanced posting can help with improving the notification system. They stated in the previous questions that some of signs are very close to the bridge that has weight restriction enforced which gives the truck driver very short distance to react to the situation. Nearly 5% of the respondents mentioned that sign related improvements such as sign visibility and use of standard signs across the state is required to improve their notification system.

Finally, about 39% of survey participants stated that their current notification system is sufficient, and no modification is required at this time.

Table 6. Required Modification to Improve Current Notification Procedures in USA

S.N.	Important Modification for Improved Notification Procedures	Percentage
1.	No modification is required	39.0%
2.	Introducing Mobile App / Website	34.1%
3.	Increase Public Awareness	14.6%
4.	Advance Posting	7.3%
5.	Sign related modifications	4.9%

Next, survey partakers were asked what is missing to implement an effective notification system at their states. About 30% indicated that electronic source of notification such as online website or mobile application is currently missing at their states. Furthermore, approximately 16% of participants reported that lack of sufficient resources including funding and staffing is standing in their way of implementing effective notification system at their states. However, 9.3% related issue to administrative procedures which included the lack of unified database of all the bridges within the state, inconsistent reporting applications and the lack of proper documentation of notification procedures. Advanced posting was another missing requirement for implementing effective notification system reported by about 5% of the respondents. Furthermore, 2.3% of the survey respondents stated that each of the following: driver education, secondary form of notification and improved enforcement systems by increasing penalties on violators are missing to implement effective notification systems at their states.

Finally, the findings revealed that to which they responded as follow, approximately 32.6% of the respondents stated that nothing is currently missing to implement effective notification system at their states, as shown in Figure 39.

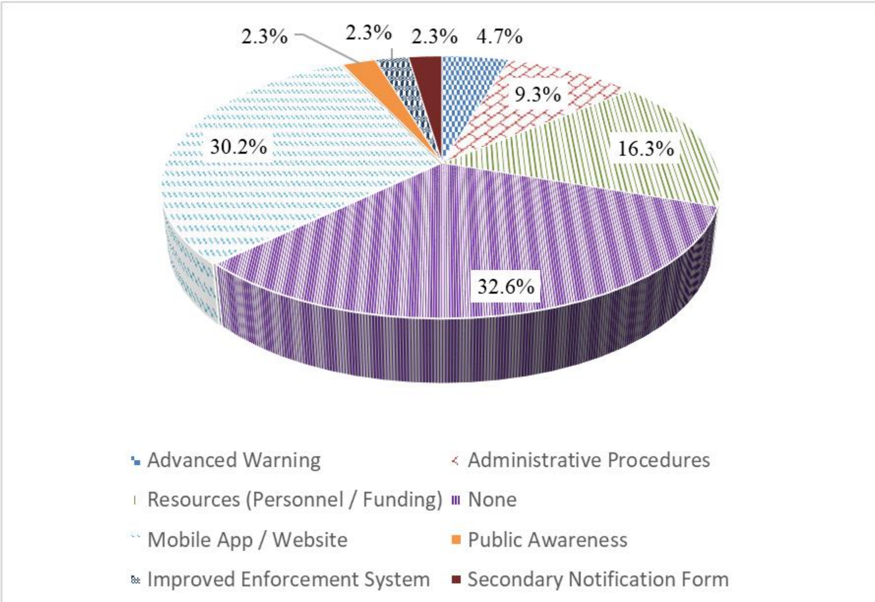


Figure 39. Requirements to Implement Effective Notification System

In the last question in the notification part, survey participants were asked whether there are any plans to develop a more effective notification system. As presented in Figure 40, over two-third of the survey partakers (about 68%) stated that their existing notification system is sufficient and that there are no current plans to develop more effective notification system. While about 11% indicated that they are currently investigating viable options but nothing specific have been offered yet. Additionally, 8% of the survey respondents mentioned that they are planning to have mobile application or live website to better notify truck drivers of bridge load postings at their states. Moreover, 5% of the participants revealed that they are planning for increased outreach programs to educate truck drivers of load signs. Another 5% of the participants cited that the development of electronic system for auto-routing or pre-routing is planned at their state. Finally, 2.6% stated that better communication channels with relevant stakeholders (specially bridge owners) is planned to develop more effective notification system at their state.

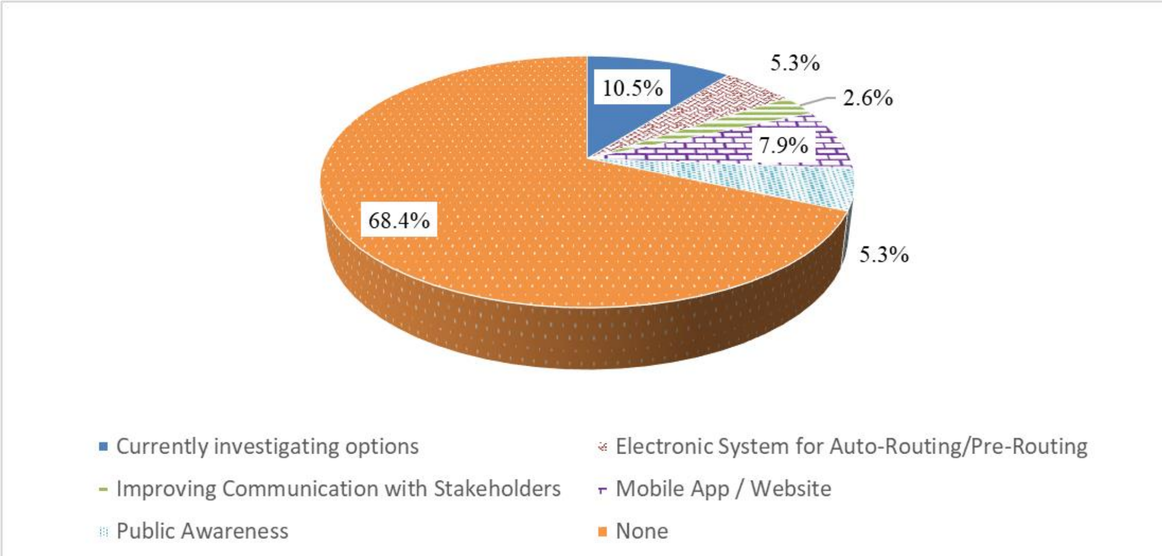


Figure 40. Plans to develop More Effective Notification System

5.2. Analysis of Section 2: Enforcement Systems/Procedures to Communicate and Administer Bridge Load Postings

In the second section of the survey, the enforcement section, participants were asked to report the current technologies and procedures used to enforce bridge load postings at their states. As shown in Figure 41, the findings indicated that static weighing is the most used technology to ensure compliance with of bridge load posting (reported by about 34.% of participants), followed by high-speed weigh in motion (WIM) reported by 23%, then low-speed WIM reported by 16%. Moreover, 14% (others) indicated that they used portable scales, while 9% indicated that they use bridge WIM and finally 4.5% are using on-board weighing (OBW).

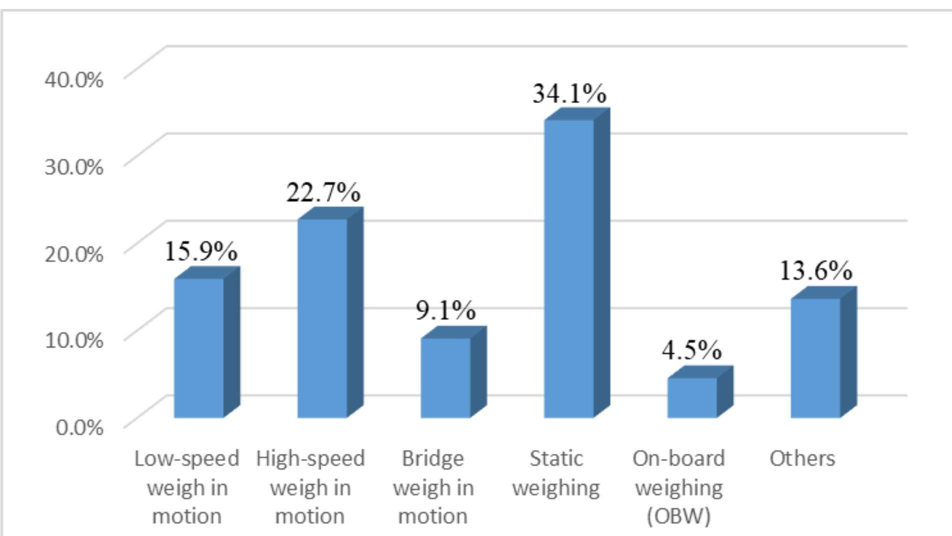


Figure 41. Current Enforcement Technology Used for Bridge Weigh Monitoring in the US

Additionally, 40% of the respondents stated that they use one enforcement technology, whereas 30% are using two different enforcement technologies. Moreover, 10% of the respondents indicated that they use three different enforcement technologies, and the same percentage (10%) is also for both four and five different enforcement technologies as shown in Figure 42.

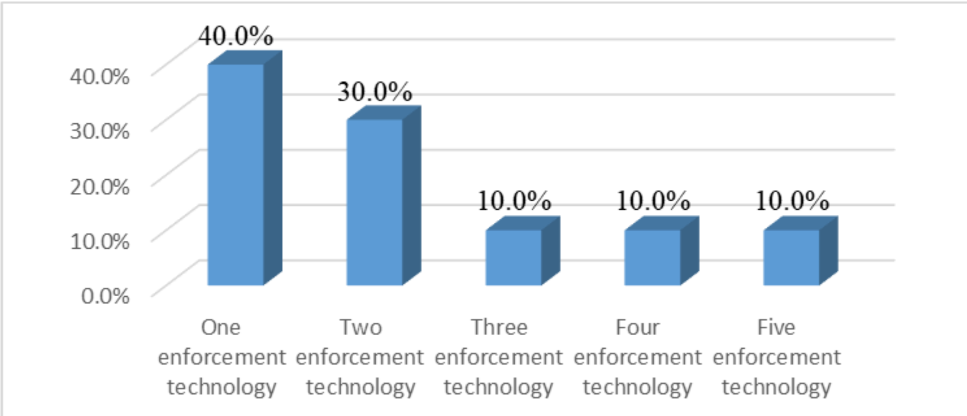


Figure 42. Number of Enforcement Technologies Used

The second question was whether WIM is used for direct enforcement of bridge load posting. As shown in Table 7, it was found that about 46% are using WIM for direct enforcement while about 54% of respondents are not using WIM for direct enforcement.

Table 7. WIM usage for Direct Enforcement at US State

S.N.	Is WIM Used for Direct Enforcement at Your State?	Percentage
1.	Yes	46.2%
2.	No	53.8%

The third question discussed the type of sensor used in WIM. As shown in Figure 43, the results indicated that about 46% of respondents are using at Strip sensor (Piezo-electric / Piezo-polymer / Piezo-quartz) while approximately 39% are using Plate sensor (Bending Plate / Load cell device).

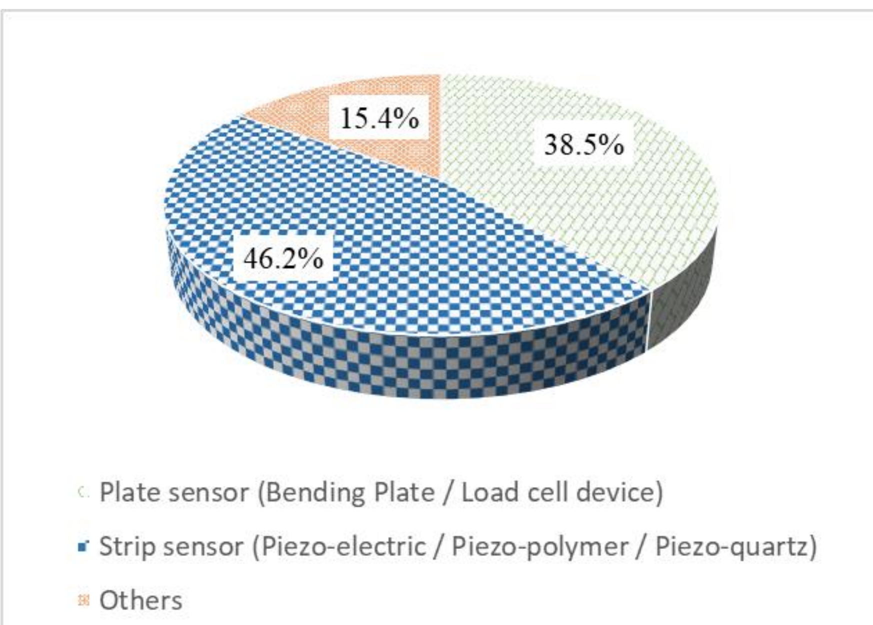


Figure 43. Sensor Type Used in WIM

Survey participants were then asked about the sensor type used in OBW. The survey participants indicated that they are not sure of the OBW sensor type that is used for direct enforcement.

Next, the State DOTs were asked about the current procedures for enforcement methods at their state, in which all survey participants indicated that they follow the state enforcement procedures. If high-speed WIM system is available, then the system uses sensors embedded in the roadway to sort out commercial vehicles suspected of overweight. Suspected vehicles are then directed by electronic signs or transponder signal into nearby weigh station for a more accurate reading of the vehicle weigh. If the vehicle is conformed to be overweight, then a warning or a fine is issued by the law enforcement unit. Some states also have weigh stations at Points of Entry (POE) along freight route, thus making sure that all commercial vehicles pass through the highway and into the weigh station for inspection. Finally, some states also indicated that patrol officers have portable scales in their units to stop any commercial vehicle suspected of being overweight. If the vehicle is confirmed to be overweight, then the officer can issue a warning, issue a fine, or force the driver to unload some of the weigh to bring the vehicle weight to the legal load before moving on. Approximately 31% of the responding States are using portable scales and another 31% are using weigh stations in addition to portable scales. There are also 23% that have WIM, weigh stations and portable scales. Moreover, there are 7.7% that have weigh stations only and another 7.7% that have WIM in addition to weigh stations as presented in Figure 44.

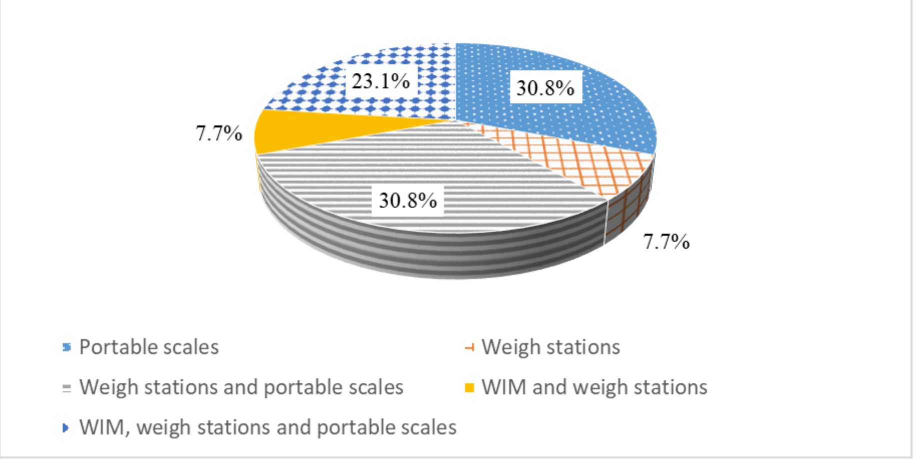


Figure 44. Current System(s) used for Enforcement in each State.

Survey participants were then asked about the frequencies of enforcement methods used in each State. It was found that about 56% of the states are using the enforcement method on daily basis while 25% are using it as needed (Others). However, about 13% reported that they use the enforcement methods few times per week, 6% are using them on weekly basis while no state is using these methods on monthly or yearly basis as shown in Table 8.

Table 8. Frequencies of Enforcement Methods in US states

S.N.	Is WIM Used for Direct Enforcement at Your State?	Percentage
1.	Daily	56.3%
2.	Others	25.0%
3.	Few Times Per Week	12.5%
4.	Weekly	6.3%

S.N.	Is WIM Used for Direct Enforcement at Your State?	Percentage
5.	Monthly	0%
6.	Yearly	0%

Survey participants were then asked to report the frequency of maintaining and calibrating their enforcement technologies. As shown in Figure 45, about 63% of participating states are maintaining and calibrating their enforcement technologies once a year whereas 25% are maintaining and calibrating their technologies twice a year and 13% are calibrating and maintaining them as required. It is worth mentioning that no state is calibrating and maintaining their enforcement technologies on weekly or monthly basis.

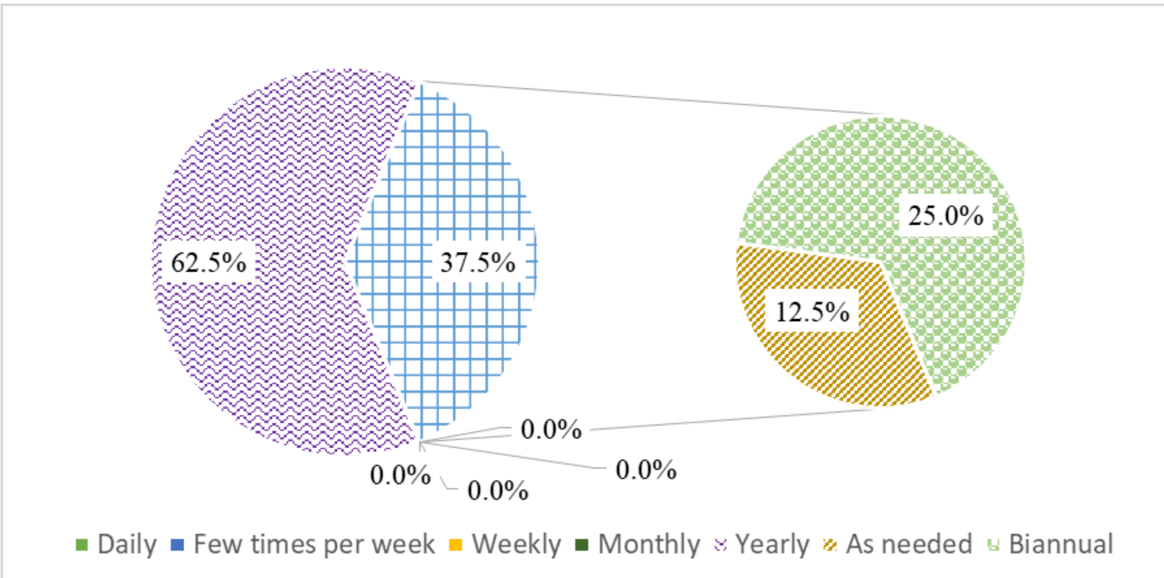


Figure 45. Frequencies of Maintenance and Calibration Process of the Enforcement Technologies in each State

Then, survey participants were asked if their states have any plans for developing more efficient enforcement systems/procedures to ensure vehicles' compliance with Bridge Load Postings at their state. As shown in Table 9, the results revealed that only 25% of the respondents reported that they do in fact have plans to develop more efficient enforcement systems such as upgrading existing weigh stations and increasing the number of WIM systems in their state whereas 75% indicated that they do not have any plans to develop more efficient enforcement systems/procedures at the moment.

Table 9. Plans to develop More Effective Enforcement Systems

S.N.	Plans to develop More Effective Enforcement Systems	Percentage
1.	Yes	25%
2.	No	75%

The final question in the survey asked the participants to list any missing requirements to implement more effective enforcement procedure. As shown in Figure 46, about 32% of survey participants stated that increased enforcement personnel are needed to ensure more coverage. In addition, 18% of the participants reported that increased funding will help in providing more physical presence on the ground at fixed and mobile weigh stations. Also, about 9% recommended that additional WIM facilities are needed while 4.5% of the respondents indicated that upgrading of existing facilities can help in effectively improving their enforcement procedures and the same percentage was also reported for both increasing fines imposed on violators as well as providing enforcement officers comprehensive training. On the other hand, about 27% of survey participants claimed that current enforcement procedure is adequate and that nothing is currently missing.

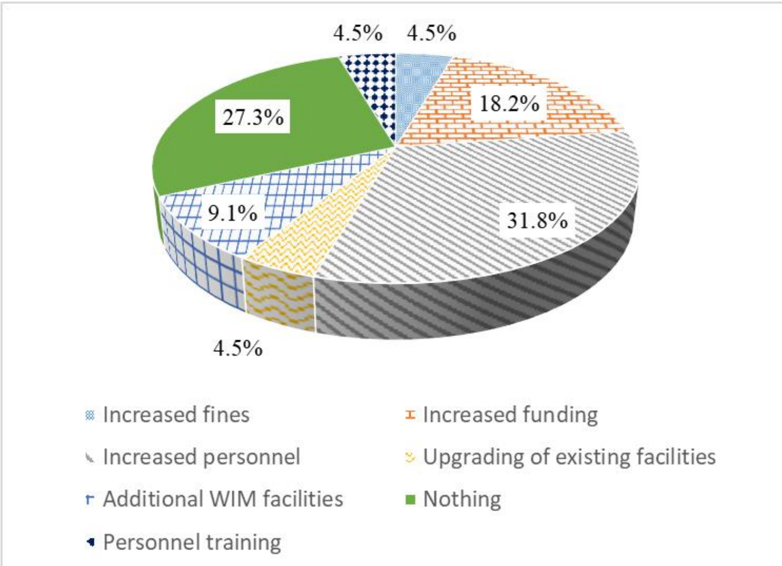


Figure 46. Requirements to Implement Effective Enforcement System

5.3. GAP ANALYSIS

5.3.1. Current Status of Notification and Enforcement Systems in the US

With regards to the notification systems in the US, it was found that overall, majority of the States (about 90%) are following a unified specification for bridge load rating and posting which is the AASHTO MBE while the remaining percentage are following local guidelines that are based on the AASHTO MBE. Similarly, most of the States (approximately 80%) are using the MUTCD as their specification for signages related to load posting while the remaining percentages are using MUTCD manual supplemented by the State's own guideline.

The survey indicated that when it comes to the frequency of administering the load rating analysis a lot of States (close to 87%) are not complying with the recommended frequency period by the NBIS (which is once every two years as presented in the literature review (1)). Instead, they conduct the analysis when a bridge's structural condition changes or whenever needed. By doing so, a bridge that is weakened by daily traffic could go unnoticed if does not show signs of deterioration. Thus, becomes a risk to the safety of the public using that structure and a hazardous site for an imminent accident.

The survey also showed that around 25% of the States are only using bridge load posting signs to notify the public of the legally permissible load at any bridge while the remaining three fourth are going further by using the signs in addition to other posting methods such as online map, booklet and 511 systems. But very small percentage of the States (8%) are using smartphone applications / mobile apps to notify drivers of bridge load posting. The other 92% of the States do not have mobile application to notify the public of bridge load posting. This unutilized tool is very important nowadays as drivers are becoming more dependent to plan their trips using their smartphones or navigation systems.

Enforcement system in the US requires some improvement to be more effective at monitoring and enforcing bridge load posting as only 30% of the US States are using three or more different method for bridge load enforcement while the majority (70%) are using only one or two different methods. Using different methods to enforce bridge load posting can help identify more violators as different technologies has different advantages, however, it is important to take into consideration the level of accuracy that each method provides when assigning the threshold that will be used to detect violators. There are a lot of technologies used to conduct bridge weight enforcement in the US, the most popular method is static weighing which is used by more than one third of the States (approximately 34.1%).

The survey presented that less than half of the States are using WIM for direct enforcement (around 46% only). The survey also revealed that around 56% of the States conduct daily enforcement of bridge load posting while 25% do not follow a specific schedule and 12.5% conduct their enforcement a few times per week.

Also, it appears from the survey that three fourth of the States (75%) are satisfied with their current enforcement methods and do not have plans to develop or improve them at least in the near future.

5.3.2. Limitations of US Notification and Enforcement Systems

In general, almost all the States are following the minimum requirements when it comes to the notification and enforcement systems of bridge load postings. However, there are several limitations and areas that needs improvement as listed below.

The limitations of the bridge load notification systems in the US could be divided into five categories as follows:

- Limitations due to lack of awareness: Load posting signs (truck weights and configurations restrictions) could be challenging for drivers to understand, as mentioned earlier, the MUTCD uses tons while the industry is using thousands of pounds. So, more awareness is still needed to improve drivers understanding with load posting signs.
- Limitations due to driver related factors: Not all drivers comply with the posted load signs, some choose to simply ignore these signs due to many reasons for example, lack of enforcement in the area or knowing that violators are not punished harshly enough.
- Resources / Administration Limitations: The posting procedure is time consuming and there is a lack of cooperation among administrators to share weight restriction data out of fear of State liability for inaccurate data.
- Signages Limitations: Although majority of the States use MUTCD guidelines or guidelines based on MUTCD. Still, signs inconsistency among the States is still an issue to truck drivers that often cross multiple States as part of their route.
- Technology Limitations: Access to online posting methods is limited due to the non-availability of such method at each State.

While the limitations of bridge load enforcement systems in the US could be divided into four categories such as:

- Facilities Limitation: There are a few numbers of permanent facilities to enforce bridge load posting in each State which limits the effectiveness of enforcement systems as less vehicles are monitored due to the limited facilities.
- Technology Limitations: A lot of States depend on only one enforcement method and that is the mobile enforcement unit. The unit uses static weighing to monitor and enforce bridge load posting. However, this process is time consuming for both the enforcement officers and truck drivers alike
- Resources Limitation: Almost all the States do not have officers dedicated to enforcing bridge load posting. Instead, this task is assigned as one of the duties of highway patrol officer / public safety officers.
- Administration / Procedure Limitations: The fines that truck drivers incur for overweighing is considered very light when compared to the damage that may be caused to the bridge and to the cost of rehabilitation if needed.

In Louisiana specifically, the main limitations were related to administration / procedure limitation and technology limitation. It was stated that posting procedure takes significant time to be updated.

Additionally, it was mentioned that online posting in the form of a mobile app or website is also missing.

5.3.3. Way Forward for Improved Notification and Enforcement Systems in the US

In order to improve the bridge load posting notification and enforcement systems in the US, each of the limitations listed above needs to be addressed and resolved. Starting with the required modifications of the bridge load notification systems in the US:

- Public Awareness: By providing truck drivers workshops to help them better read and understand load signages. Additionally, by educating truck drivers about the importance of obeying load signages and that they do not have to comply with the posted weight limit out of fear of traffic fines but because great risks could occur if they do not conform to the legal weight limit. Moreover, if a bridge becomes too weak and then closed by the State, their route could increase significantly thus wasting a lot of time and resources.

- Administrative Procedures: By increasing cooperation and communication levels between bridge owners (specially for private owners) and the departments within State DOTs responsible for conducting bridge load rating analysis, identifying the appropriate load posting signs, and maintaining accurate database. Which will help in completing the procedure more efficiently and reduce the time required to complete these tasks. Moreover, using technology to document, record and communicate among stakeholders will ensure appropriate accountability for each stakeholder during the whole process.

- Signages Related: By using clear and consistent bridge load signs among all States making it easier for truck drivers to understand. In addition, by increase the number signs via advance warning signs that can be very helpful to truck drivers to better adjust their route instead of reaching the bridge location.

- Technology Utilization: By adopting notification methods that rely on technology such as providing easily accessible and user-friendly interactive maps. Furthermore, by developing a universal platform / mobile application that includes bridge weight restriction information not only on a state level but nationwide to cover the whole US.

- Additional Notification Methods: By investing in multiple bridge load notification methods to reach a wider range of truck drivers as well as by adverting the available notification systems to get the maximum advantage out of them.

While the modifications needed to improve the bridge load enforcement systems in the US are as follow:

- Additional Facilities: By increasing the number of permanent enforcement facilities in each State to cover a wider area in each State.

- Technology Improvement: By utilizing state of the art related enforcement technologies such as high-speed WIM and upgrade the enforcement technology in existing facilities. Such improvement will reduce enforcement procedure timing as well as increase the number of trucks that are checked for weight limit compliance.

- Additional Resources: By increasing the funding that goes into enforcement procedures, such as having dedicated well trained officers to administer bridge load weight enforcement.

- Improve Administration / Procedure: By imposing strict fines on weight limit violators not only in terms of money but also suspension of the truck used in the violation and the commercial driver license for some period of time. Sending a message to other drivers not to take bridge load posting very lightly and making first time violators think twice before ignoring legal weight limit again.

7. CONCLUSIONS

A load rating analysis is the first step that is performed to estimate a bridge's live-load carrying capacity. If the operating rating factor falls below one, load posting is required. Signages are used to notify drivers about bridge load postings. If a vehicle is overloaded, it will deteriorate bridges' capacity due to increased live-load. That is why enforcement system is a necessary step to reduce overloading vehicles from driving on bridge.

Regular inspection of bridges is vital to check if bridges can carry the permissible load or not and whether a weight restriction is necessary. It is the responsibility of bridge owners to inspect the bridge and implement any posting required. Truck drivers depend on the bridge owners in keeping bridges safe and sound for their use. So, bridge owners should regularly conduct load rate analysis and, if necessary, install appropriate postings.

The main objectives of this study were to identify and suggest plausible notification systems that effectively communicate bridge load postings to dispatchers and drivers, investigate and suggest possible approaches to communicate potential detour routes, and identify corresponding enforcement methods required to successfully administer bridge load postings

To better achieve the objectives of this study, a national survey study that targeted DOT professionals and State employees working in enforcement agencies was conducted to obtain their valuable insights and feedback regarding the current notification and enforcement systems in the US states. The online survey consisted of two parts, the first part was about notification procedures and the second part was about enforcement procedures.

After careful analysis of the survey data, it was found that:

- Majority of the responding States (around 87%) are conducting load rating analysis only when a bridge's structural condition changes or as needed instead of the NBIS's recommended frequency period, once every 24 months (1),
- The main limitations of current notification systems were administration related, awareness related, drivers related, resource related, signages related and technology related,
- While some of the main modifications needed to improve the current notification systems were to introduce mobile applications, provide public awareness and advance posting,
- WIM is used for direct enforcement in nearly 50% of the States participated in the survey,
- Some of the main modification needed to improve the enforcement system were to increase the number of personnel, increase the funding, and increase the number of WIM facilities.

In addition to the online survey, there are a lot of lessons to be learned from the evaluation of some of the best practices used internationally such as:

- WIM system will remain a key component for enforcement policy as statically weighing every vehicle is not realistic. For efficient enforcement procedures, high speed WIM may be used for preselecting potentially overweighed vehicles
- Whereas low speed WIM and OBW systems may be used for direct enforcement as both systems provided good accuracy levels. Although, the use of OBW devices can play a

crucial role in ensuring that vehicles are not overloaded (axle overloading) by accident. As axle overloading is the dominant type of overloading in long-distance transport (59).

- Slovenian bridge WIM system (SiWIM) which uses strain gauges to capture bridge deflection measurements is considered to have very good accuracy levels and can be used on wider range of bridge types including short concrete slabs and long-span bridges (57).
- The Dutch use high-speed, multiple-sensor WIM system for direct automated enforcement of overloading since the system was able to achieve their required accuracy level (57).
- France tested VIDEO WIM systems to study the possibility of fully automating the enforcement of load posting. The system processed the data and was able to identify overloaded vehicles in real time with a high accuracy level of 81% (5).

There are many methods than can be used for possibly communicate potential detour plans, these options can be divided into pre-route and en-route. Website posting and 511 phone service are example of pre-route options while portable CMS and HAR are examples of en-route option. The pre-route options were found to provide more information about potential detour plans however, they require smartphone/internet access. On the other hand, en-route options provide concise information without distracting the driver by having them use their smartphone while driving, additionally, the portability of these options allow them to be used at different site locations.

Effective notification and enforcement systems will help decrease overloading rate with time. Thus, prolonging the life cycle of bridges, one of the most critical and expensive transportation infrastructures, and saving a lot of resources that would be required for rehabilitation of bridges. Therefore, below are some recommendations that can help improve the efficiency of existing notification and enforcement systems. It is advised to

- Comply with NBIS's recommended frequency for bridge load rating analysis by conducting load rating analysis at least once every two years.
- Include advance warning signs to allow truck drivers sufficient time to adjust their route.
- Use more than just one notification method besides posted signages to reach a larger group of truck drivers and inform them about the legal weight limit of bridges.
- Use more than just one enforcement method as different methods has its own advantages. Additionally, increasing the number of different methods may lead to increasing the enforcement frequency. The use of SiWIM and VIDEO WIM in the US can significantly help in increasing the number of trucks tested against permissible load posting as these systems process data in very short time with very good accuracy.
- Make sure of integrated communication and cooperation between relevant stakeholders including law enforcement agencies and bridge owners (private and public owners).
- Develop a central database in the form of online map/mobile app that includes posting information of all the bridges in the US. This national scale database will help truck drivers especially ones that are crossing multiple States. It will ensure consistency of the way information is presented and allow drivers to better plan their route from one platform instead of having to switch to different platforms whenever they cross to a different State.

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APPENDICIES

Developing Notification and Enforcement Systems to Communicate and Administer Bridge Load Postings

Introduction

You are invited to participate in a survey on "**Developing Notification and Enforcement Systems for Load Rating and Posting of Bridges"**. This survey has been developed by the researchers at Louisiana State University, United States of America (USA). The main objectives of this survey are to:

- Identify existing and/or new notification systems that effectively communicate bridge load postings to dispatchers and drivers.
- Identify existing and/or new corresponding enforcement methods required to successfully administer bridge load postings.

It is expected that the results of this project could pave the way for developing notification and enforcement systems to communicate and administer bridge load postings in Louisiana and elsewhere.

The survey is intended for DOT professionals who have relevant expertise with this area of research. The data collected from this survey will be analyzed and the results will be disseminated in peer-reviewed journals and conferences. The survey should take approximately 10-15 minutes of your time, however, for some it could take longer. We hope that you find the experience to be informative and engaging.

Inclusion Criteria:

To participate in this study, you MUST meet the following two requirements:

- Currently work at US departments of transportation or other US transportation authorities such as NHTSA or FHWA.
- Have at least 3 years of experience in the field of transportation engineering or Intelligent transportation systems.

Potential Benefits:

An immediate benefit for this research is to assist Transportation agencies such as Louisiana Department of Transportation and Development (LADOTD) to create the necessary roadmap to develop notification and enforcement systems to communicate and administer bridge load postings.

Confidentiality:

All collected responses will be treated with the utmost confidentiality and stored securely in facilities that belong to Louisiana State University (LSU). In our work, no effort will be made to identify respondents to the survey including linking with other data sets that could help in this regard. The data will be kept on an encrypted drive hosted at LSU, which is accessible only by members of the research team (PI and his graduate student only). The data will be kept for a minimum of two years and will be used for further analysis and publication.

Participation and Withdrawal:

Your participation in this study is voluntary. It is your choice to be part of this study or not. If you decide to be part of the study, you can stop (withdraw) from the survey for whatever reason. Your data will be permanently removed from the database. However, it should be noted that once survey results are submitted, withdrawal is not possible because your data are anonymous.

Information about the study results:
This study will be completed by January 2022. The results will be then prepared in a technical report that will be hosted on the Transportation Consortium of South-Central States (Tran-SET) UTC website (http://mitl.mcmaster.ca/research#Reports) by Feb. 2022.

Questions about the Study:
If you have questions or need more information about the study itself, please contact the PI of this project: Dr. Hany Hassan, assistant professor of transportation engineering, LSU (hassan1@lsu.edu).

This study has been reviewed by the Institutional Research Board (IRB) at LSU and received ethics clearance. If you have concern or questions about your rights as a participant or about the way the study is conducted, please contact: LSU IRB office (irb@lsu.edu)

Having read the aforementioned information, I understand that by clicking the "yes" button below, I agree to take part in this study under the terms and conditions outlined earlier

- ◯ I agree to participate in this survey (1)
- ◯ I do not agree to participate in this survey (2)

Which State you are working at?

▼

Which department within the DOT you are working at?

____

____

Section 1: Notification Systems/Procedures to Communicate and Administer Bridge Load Postings

Q1.1 Which specification is currently being used for load rating and posting of bridges at your state?

- ◯ AASHTO Manual for Bridge Evaluation (MBE), 2nd Edition (1)
- ◯ Others (Please specify): (2) ____

Q1.2 Which method is currently being used for load rating and posting of bridges at your state?

- ◯ Allowable Stress Rating (ASR) (1)
- ◯ Load Factor Rating (LFR) (2)
- ◯ Load and Resistance Factor Rating (LRFR) (3)
- ◯ Others (Please specify): (4) ____

Q1.3 Is there any software used for load rating?

- ◯ Yes (Please specify): (1) ____
- ◯ No (2)

Q1.4 Which specification is currently being used for load posting signage?

- ◯ Manual on Uniform Traffic Control Devices (MUTCD) (1)
- ◯ Others (Please specify): (2) ____

Q1.5 What is the frequency of load ratings for previously posted bridges at your state?

- ◯ 6-12 months (1)
- ◯ 12 months (2)
- ◯ 12-24 months (3)
- ◯ 24 months (4)
- ◯ Others (Please specify): (5) ____

Q1.6 What are the current methods used at your state for notifying drivers about permissible bridge loads?

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Q1.7 Is there any mobile app that is being used to communicate with drivers about the bridge load postings at your state?

○ Yes (Please specify): (1) ____

○ No (2)

Q1.8 What are the main limitations of the current procedure of notifying drivers about bridge loads at your state? (Please provide your response in detail)

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Q1.9 What are the most important modifications to improve existing notification system for bridge loads at your state? (Please provide your response in detail)

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Q1.10 What is missing in your state to implement effective notification system for bridge loads?

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Q1.11 Are there any plans for developing more efficient systems/procedures to better communicate and administer Bridge Load Postings at your state? (Please provide your response in details)

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Section 2: Enforcement Systems/Procedures to Communicate and Administer Bridge Load Postings

Q2.1 What are the current enforcement technologies used for bridge weight monitoring at your state? (Please select all that apply)

- ☐ Low-speed weigh in motion (1)
- ☐ High-speed weigh in motion (2)
- ☐ Bridge weigh in motion (3)
- ☐ Static weighing (4)
- ☐ On-board weighing (OBW) (5)
- ☐ Others (Please specify): (6) ____

Q2.2 If weight in motion (WIM) is used, is it used for direct enforcement?

- ○ Yes (1)
- ○ No (2)

Q2.3 If Weight in motion (WIM) is used, what is the sensor type?

- ○ Plate sensor (Bending Plate / Load cell device) (1)
- ○ Strip sensor (Piezo-electric / Piezo-polymer / Piezo-quartz) (2)
- ○ Others (Please specify): (3) ____

Q2.4 If OBW (On-board weighing) is used for enforcement technology, what is the sensor type?

- ○ Load cell (1)
- ○ Air Pressure Transducer (APT) (2)
- ○ Strain gauges (3)
- ○ Others (Please specify): (4) ____

Q2.5 What are the current procedures for enforcement methods at your state? (Please provide your response in details)

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Q2.6 What are the frequencies of enforcement methods at your state?

- ◯ Daily (1)
- ◯ Few times per week (2)
- ◯ Weekly (3)
- ◯ Monthly (4)
- ◯ Yearly (5)
- ◯ Others (Please specify): (6) ____

Q2.7 What is the frequency of maintenance and calibration process of enforcement technologies at your state?

- ◯ Daily (1)
- ◯ Few times per week (2)
- ◯ Weekly (3)
- ◯ Monthly (4)
- ◯ Yearly (5)
- ◯ Others (Please specify): (6) ____

Q2.8 Are there any plans for developing more efficient enforcement systems/procedures to ensure vehicles' compliance with Bridge Load Postings at your state? (Please provide your response in details)

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Q2.9 What is missing in your state to implement effective enforcement procedure?

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