FUSION OF WIM AND PERMIT DATA



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Abstract
US Departments of Transportation (DOTs) and federal agencies collect vehicle permit and weigh-in-motion (WIM) data. These two unique data sources are rarely used together for a full understanding of route-specific freight travel. Data fusing is challenging, but it may improve knowledge of the freight network and roadway loading. The objective of this paper is to review information on both permitted and WIM traffic data and discuss how they can be used together to better understand and respond to highway infrastructure needs. A large volume of traffic data from these two sources is available and may be utilized, but there is a need to develop or improve procedures for processing massive traffic data between these sources. This involves the development of efficient filtering procedures, processing tools, and algorithms to analyze the data. Fusion of WIM and permit will result in improved advanced knowledge of freight travel characteristics which can help implement programs to assess the damage on pavements, and bridges, strengthen enforcement of the traffic flow, and enhance the safety of freight movements. Comprehensive knowledge of vehicle characteristics will help design engineers make the proper adjustments to improve the longevity and safety of infrastructure.

Keywords: WIM, permit, fusion, overloaded trucks, bridge, traffic loads, infrastructure, big data.

1. Introduction

Traffic data is an important source of information required for the efficient management of roads and bridges. This includes not only the actual number of vehicles, their weight, axle configuration, and multiple presence, but also trends in traffic changes over the years which are needed for the prediction of future loads. Highway traffic is site-specific, therefore, there is a need for knowledge of the traffic in various locations, representative of the state. Traffic includes a mix of vehicles, from lightweight cars to heavy legal trucks, overweight and super load permit vehicles, and also illegally overloaded vehicles. It has been observed that there is considerable growth in the number of overloaded and permitted vehicles so that they can be considered regular traffic. Thus, there is a need to monitor this segment of traffic on a continuous basis to determine the actual traffic and observe changes that can help in predicting future traffic trends and required construction and maintenance activity.

Traffic data can be collected using direct in-place manual counts, dedicated periodical or continuous traffic counts by traffic counters, traffic signal loops data, Weigh-in-Motion (WIM) stations, permit records, transport demand models, and so on. The quantity and quality of recorded information can vary depending on the utilized data collecting technique. Weigh-in-Motion stations are considered the most effective sources of information on massive traffic data. The records are collected automatically without human involvement, and data sets include traffic counts and the selected attributes of vehicle speed, axle loads, and axle spacing.

Utilization of massive data collected by traffic counters requires proper quality control and assurance procedure to maintain the good quality of the data. Errors are practically unavoidable but can be easily detected by cleaning data procedures and disregarding unreliable records. Therefore, it is important to monitor the quality of data recorded by Weight-in-Motion stations. Many parameters may affect the quality of WIM data such as weather, power supply defects, sensor decalibration, and so on. In the US state DOTs collect massive WIM data, which can be estimated as over 100 million records per year.

The permit data is collected through automatic permitting systems specific to every state. DOTs issue permits for overloaded and oversize vehicles. The records include permit type, vehicle configuration, and axle loads. It also contains the trip origin and destination and possible routes of permit vehicle operations. Permit data allows detecting and monitoring of heavy traffic corridors, defined by road pavements and bridges used for permit vehicle operation. The permit records combined with WIM data can serve as a useful source of traffic validation and in consideration of future policies for road and traffic management.

Numerous areas such as traffic analysis, design, repair, and maintenance, as well as management could benefit from the proper fusion of permit and WIM data. This fusion will result in improved knowledge of freight traffic characteristics. The massive traffic data can be utilized to determine the damage caused by overloaded permit trucks on bridges and pavements, help to enhance the safety of freight movements, and advance enforcement practices. The improvement of road safety is the most important benefit. Having a better understanding of vehicle weight, configuration, volume, and traffic trends by utilizing WIM and permit data can improve durability and road safety.

2. Background

Analysis of traffic-induced load effects is essential to maintain the safety of infrastructure. Therefore, the existing traffic volume and load effects must be continuously monitored and evaluated. Traffic weight data can be utilized in the design and evaluation of bridges and pavements. Nowadays, there are several techniques to measure traffic-induced loading, including static and in-motion measurements.

The static methods are local, and selective and measure only a small fraction of the highway network traffic. Static measurements can be performed by portable scales and weigh stations. Weigh stations are located off-road and typically have static scales built into the pavement. In these systems, an operator checks if the legal weight limits have been violated. Furthermore, weigh station locations are known by truck drivers, and illegally overloaded vehicles may try to avoid them, resulting in biased truck weight data. WIM measurements enable continuous recording of vehicles passing a measurement site. The WIM systems can collect traffic volume, vehicle configurations, and load spectra. It is a powerful tool to collect a massive traffic database. Data are recorded for every vehicle, including a detailed description of vehicle configuration, vehicle class, measurement date and time, occupied lane, trip direction, moving speed, and truck axle weights and spacings.

To accurately assess traffic-induced load effects, it is required to verify the data quality. There are uncertainties involved in the measurement process that must be considered while dealing with big data. Assessment of the live load effect plays a key role in designing and evaluating roads and bridges to maintain the infrastructure's safety. Hence, it is vital to adequately assess the load effects not to underestimate or overestimate the load effects. Underestimating the live load effect can cause premature damage, and overestimation can cause a significant cost increase.

There are many studies considering quality control checks of traffic data (Anitori et al. 2017; Elkins and Higgins 2008; Fiorillo and Ghosn 2014; Kulicki et al. 2015; OBrien et al. 2021; Ramachandran et al. 2011; Sivakumar et al. 2008). However, there is no uniform Quality Control procedure. All states gather traffic data as part of FHWA's Highway Policy Management System, and the quality has to meet the minimum requirements prescribed in the guides (Quinley 2010). The quality and quantity of traffic data for bridge design and evaluation purposes have been examined extensively (Ghosn et al. 2011; Sivakumar et al. 2008). The changes in truck traffic volume, axle load, and configuration in recent decades are reviewed by (Anitori et al. 2017; Ghosn et al. 2011; Liao et al. 2015). Many researchers utilized WIM data to account for the site-specific nature of traffic and develop more efficient bridge designs (Ali et al. 2020; Anitori et al. 2017; Leahy et al. 2015) to evaluate existing bridges (Hayworth et al. 2008; Lawson et al. 2013; Minervino et al. 2004; Stawska et al. 2021) and for fatigue studies (Chotickai and Bowman 2005; Iatsko et al. 2020; Stawska et al. 2022; Treacy and Brühwiler 2012).

Moreover, the number of issued overloaded permit vehicles is growing on an annual basis. US DOTs are concerned about permit load effects on infrastructure. To evaluate the impact of permits, it is necessary to evaluate the traffic data and its effect on structures. The WIM and permit database is essential to assess load-induced effects. The calculation of the load effect can be challenging when dealing with massive traffic data. Currently, WIM data is the main source of information about traffic and its attributes. Several studies utilized the WIM data to identify specific overloaded vehicles in the traffic flow to assess their load effects. This paper will focus on the potential in collection and processing of WIM and permit data, and the benefits and application of data fusion to better understand the overload freight characteristics and their impact on safety.

3. Traffic Composition

Truck weight and size limits are enacted to ensure the safety of roads and bridges. The impact of heavy traffic needs to be monitored to control wear and tear caused by heavy traffic. Federal truck weight and size law prevent states from imposing vehicle weight limits on interstate highways that deviate from established federal weight limits in the US. There are also state-specific exceptions from standard law, called grandfather provisions.

Traffic consists of various vehicle types and configurations with changing numbers of axles, variable spacings, and weights. Overall, vehicles can be grouped as **legal vehicles** that do not exceed federal truck weight and size law and state laws for axle spacings and weights and do not require a permit; **grandfather vehicles** are legally overloaded vehicles under grandfather provisions, which are old rules that remain unchanged after a new rule was introduced. Based on that, some vehicles can operate above the federal truck weight and size law; **permit vehicles**, which can legally exceed the legal limits after purchasing the permit; and **illegal vehicles**, which do not meet the regulations and exceed the weight, size, or weight and size limits. **Figure 1** shows the general traffic composition.

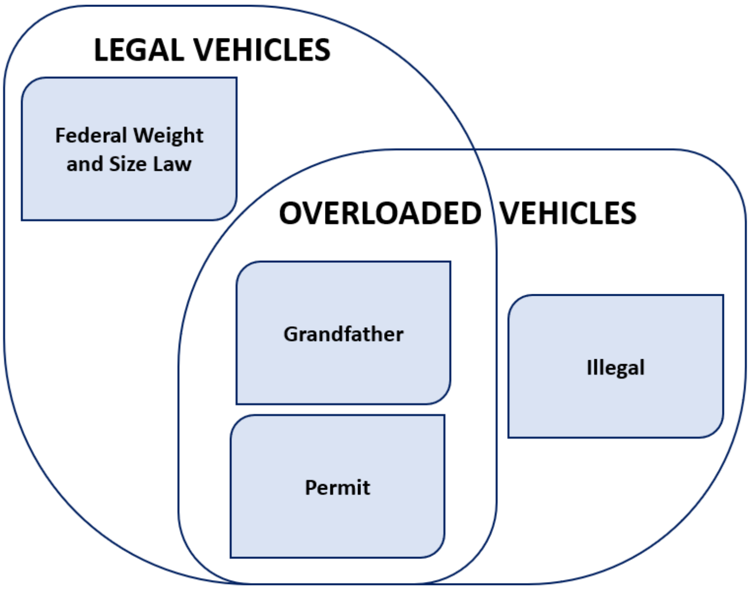


Figure 1 – General traffic composition

Grandfather provisions allow exceptions to the federal limits on vehicle weight and size. These provisions are exempt from previously existing rules. The first grandfather provision was enacted in 1956, and it deals primarily with gross vehicle weights, axle weights, and permitting practices. In 1975, federal law employed a bridge formula that limits the axle configuration and axle load distribution. Many states adopted their interpretations of weight laws under grandfather provisions, depending on local traffic conditions. The most common grandfather exemptions are for vehicles carrying agricultural and farm products and commodities. Federal Highway Administration (FHWA) reports that 41 states provide exemptions for “agricultural vehicles” (FHWA, Freight Management, and Operations, 2019).

Permit vehicles are overloaded vehicles that can operate legally after purchasing the permit. Overloaded permit vehicles can be oversized, overweight, or both. Permit vehicles need to follow the limitations specified in their permit, which may restrict the gross, single axle, and group axle weights. In the US, every state has its own policies on issuing permits but must follow federal rules. Permits allow vehicles of specific configurations and sizes to exceed the standard vehicle size and weight limitations. Permits can be issued for single or multiple trips. The permit may have limitations on designated routes, the number of trips, times of operation, and the necessity, or not, for escort vehicles. The movement of permitted oversized or overweight vehicles must also comply with the requirements and safety considerations specified by state law.

4. WIM Data

The monitoring of traffic-induced load effects is essential to maintain the safety of infrastructure. Therefore, the existing traffic volume and load effects must be continuously monitored and evaluated. WIM measurements enable continuous recording of vehicles passing a measurement site. The WIM systems can collect traffic volume, vehicle configurations, and load spectra. It is a powerful tool to collect a massive traffic database. Data is recorded for every vehicle, including a detailed description of vehicle configuration, vehicle class, measurement date and time, occupied lane, trip direction, moving speed, and truck axle weights and spacings. It is required to verify the data quality to accurately assess traffic-induced load effects. There are uncertainties involved in the measurement process that must be considered while dealing with big data. Several factors can affect the accuracy of the weigh-in-motion measurements, such as pavement roughness (causing bouncing axle movement or dynamic impact), temperature effects, multiple presences, incorrect vehicle position, etc. Assessment of the live load effect plays a key role in designing and evaluating roads and bridges to maintain the infrastructure's safety. Hence, it is important to adequately assess the traffic-induced load effects.

Analysis and processing of massive traffic data can be cumbersome, and therefore there is a need to develop efficient tools to allow systematic evaluation of the traffic. US DOTs collect immense amounts of data on a regular basis. Figure 2 presents the number of WIM records for year 2016 for selected US states. It can be noticed that there are 10-90 million WIM records collected every year. It is critical to utilize the data to better plan, predict, and understand US truck traffic. The use of big traffic data allows for a better understanding of traffic volume, its trends and fluctuation, and its impact on infrastructure. WIM data can be used in reliability-based calibration procedures to develop a live load model with specific statistical parameters and to calculate optimal live load factors for bridge design and evaluation procedures to achieve the desired safety level under existing traffic. There are many applications of the WIM data, but how to use it along with permit data?

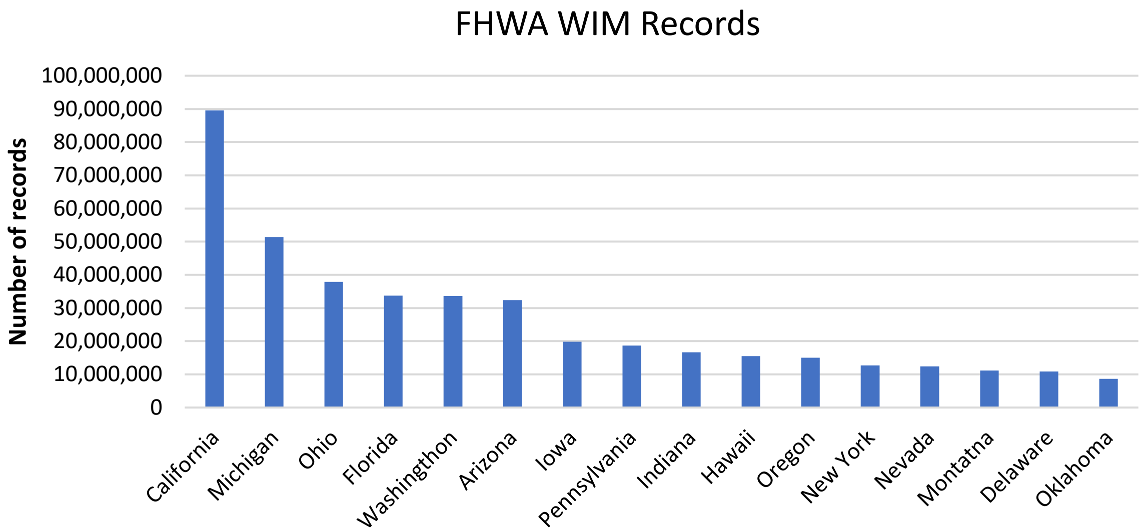


Figure 2 – Number of WIM records for selected US states.

5. Permit Data

In the US vehicles exceeding the legal limits on size and/or weight need to purchase permits to legally operate within that jurisdiction. State DOTs issue permits on a daily basis to oversize and overweight or both oversize and overweight vehicles. The permit fee structure varies significantly by state. There are typically single and annual multi-trip permits. The annual multi-trip permits are valid for 12 months and an unlimited number of trips. Single trip permits are valid from one point of origin to one destination. The permit fee criteria are very different for each state. The permit fees can be based on axle weight, gross vehicle weight, distance, weight and distance, and flat fee. The variability of permit types and fee structure also reflects the differences in the number of issued permits and their characteristics.

In the US permit data is collected by automatic permitting systems, which are state-specific. The permit data is an excellent source of information and can be used to better understand the oversize and overload traffic within the state. Permit data analytics can provide statistics about permit traffic and its trends. Permit application includes many different fields of data on each single permit vehicle. These fields include information about the specific permit type, issue date, trip origin and destination, miles traveled, authorized routes per trip, permit fee, selected route, type of carried load, and more. Most importantly permit data include vehicle characteristics such as vehicle length, height, and width, and Gross Vehicle Weight (GVW), as well as axle loads, number of axles, and axle spacings. Permit data includes detailed information about the vehicles operating within the state and can be used to determine heavy permit corridors, assess damage caused by trucks to bridges and pavements, and analyze the trends, and provide a basis for improvement of enforcement and safety. **Figure 3** presents a number of issued permits for the state of Alabama and Florida for the year 2016-2019.

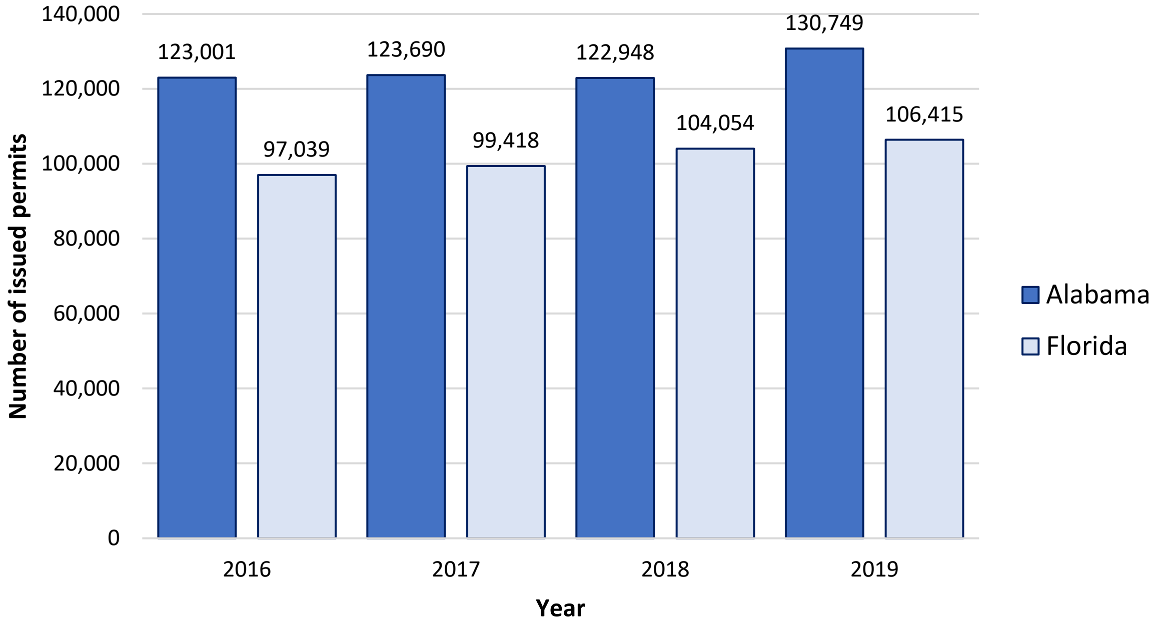
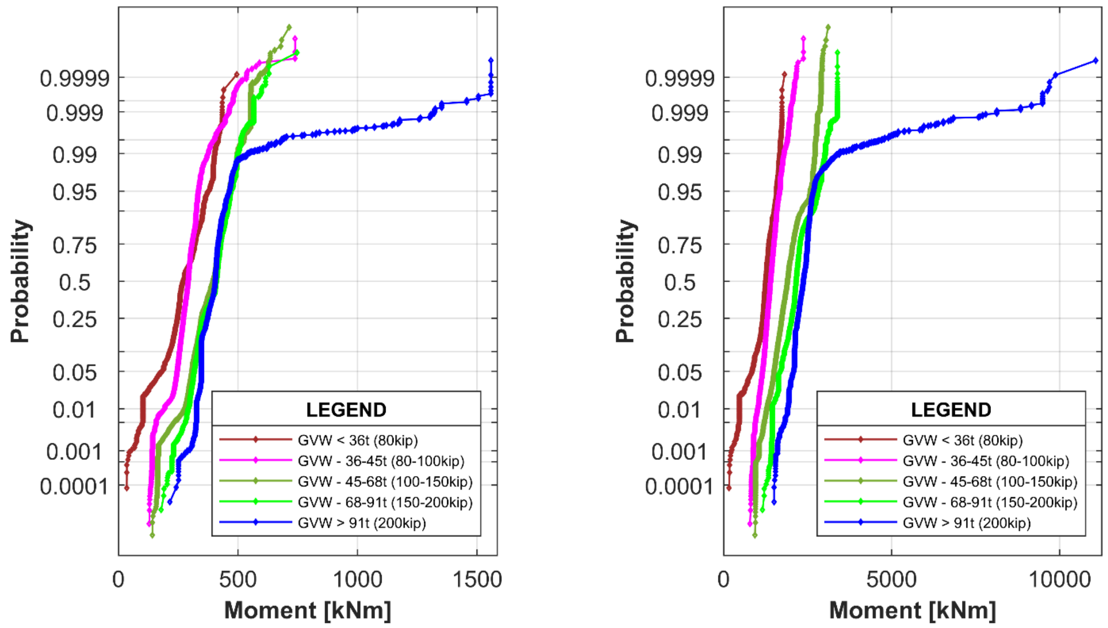


Figure 3 – Number of issued permits for Alabama and Florida for the years 2016-2019.

6. Load Effects on Bridges

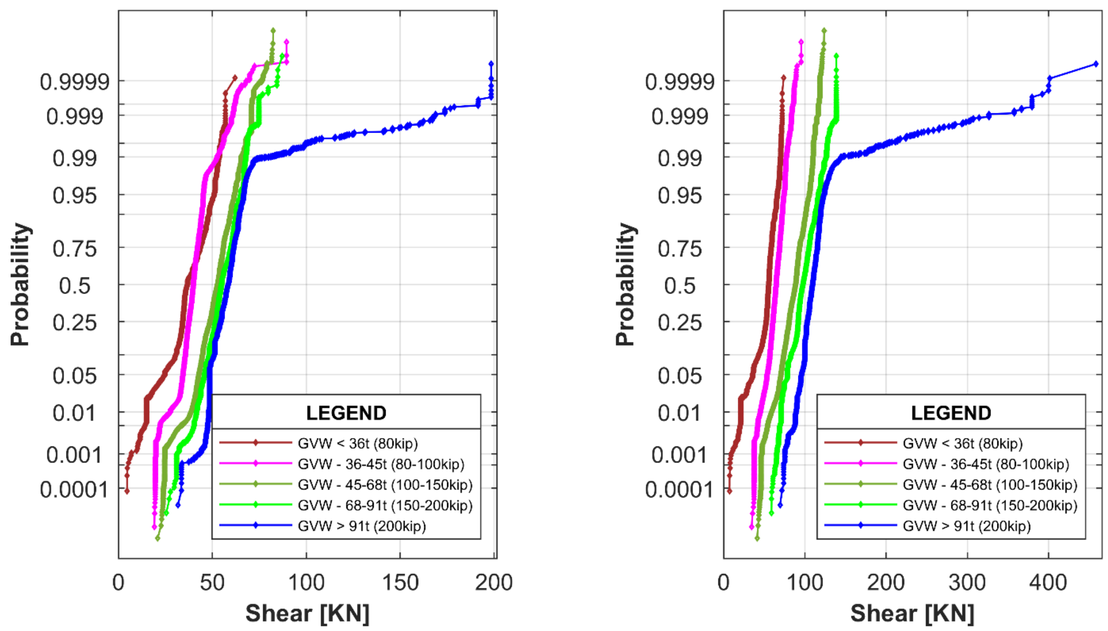
The impact of overloaded vehicles on bridges and roads is essential to assess the damage and behavior of structures under excessive loading. Regular inspections, traffic analysis, and improvement of the code provisions regarding the ever-changing live load effect are vital to protect the public's safety and maintain the required condition of road infrastructure. This section presents a calculation of traffic-induced load effects in terms of moments and shears for various types of trucks. **Figure 4** shows the moment effects of permit trucks for span lengths of 12 m (40ft), and 36 m(120ft) for various GVW, and similarly, **Figure 5** shows the shear effects. Such data representation allows graphical estimation of trucks, the most impacting bridges. For example, in a case of span lengths equal to 12 m, 1% of heavy trucks generate a bending moment exceeding 500 kNm, while in case of span lengths equal 36m, it is 3000 kNm (check red lines).

In the damage assessment analysis, GVW is not a crucial damage parameter, but the load distribution on axles and the axle spacing are critical since they decide about the load effect. Based on the overloaded vehicle characteristics, including the number of axles, single and tandem axle weight, the damage to road infrastructure caused by every single vehicle can be quantified. Figures 6 and 7 show the moment and shear distribution for various vehicles based on their axle number.



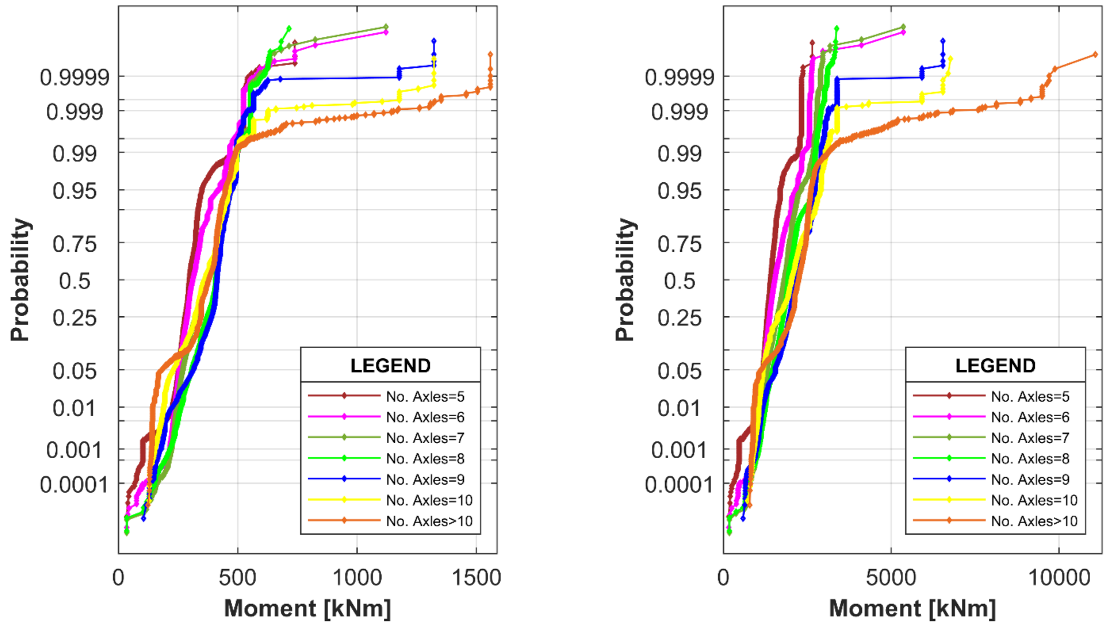
(a) **(b)**

Figure 4 – Moment effects for span length of a) 12 m (40ft), and b) 36 m(120ft) for various GVW (red lines mark 99% quantile).



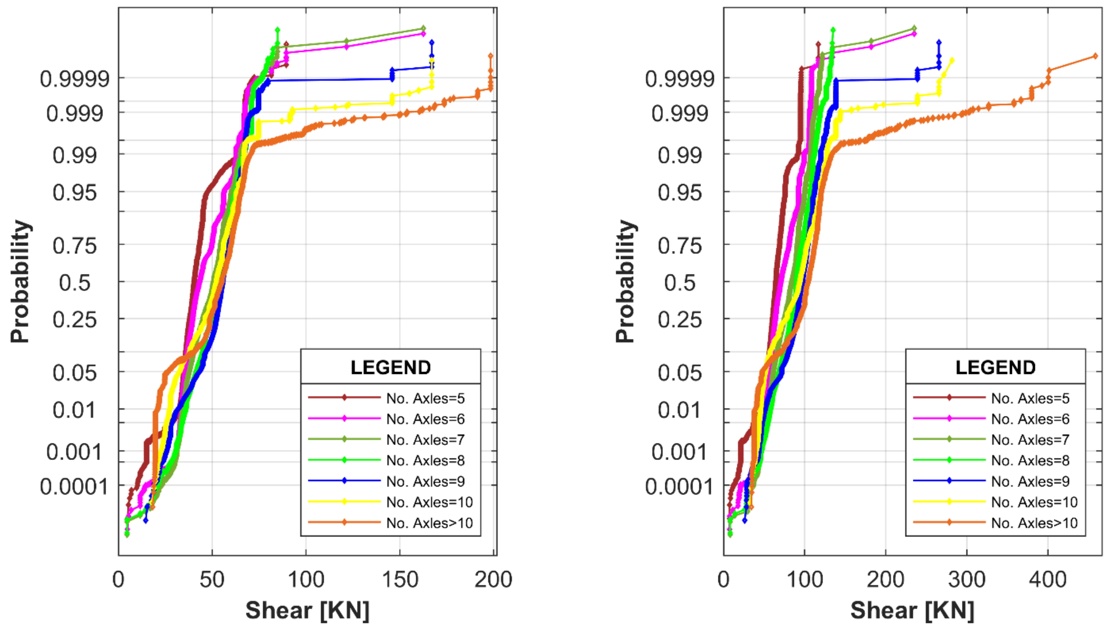
(a) **(b)**

Figure 5 – Shear effects for span length of a) 12 m (40ft), and b) 36 m(120ft) for various GVW.



(a) **(b)**

Figure 6 – Moment effects for span length of a) 12 m (40ft), and b) 36 m(120ft) for vehicles with number of axles.



(a) **(b)**

Figure 7 – Shear effects for span length of a) 12 m (40ft), and b) 36 m(120ft) for vehicles with number of axles.

The infrastructure consumption under overloaded trucks depends on a combination of axle loads, the number of axles, and spacings between them. It is important to understand the damage contribution of various vehicle types on roadways and bridges. WIM and permit data can be used to determine the load effects in terms of moments and shear for various bridge types and geometries. Periodical analysis of load effects on bridges can help bridge owners to better understand structural behavior and enhance the bridge management system.

7. Fusion of Data

In order to evaluate the impact of heavy traffic on roadways and bridges, there is a need to collect and process data that can help to assess and develop advanced models to predict structural behavior, loads, extreme events, and more. Improved understanding of long-term structural behavior through data assessment can quantify the impact of multi factors on infrastructure performance.

The Transport Demand Model (TDM) is the primary tool for forecasting future traffic demand and performance of a transportation system. The TDM is developed for evaluating large-scale infrastructure projects and they can be utilized for complex policies involving management and control of existing infrastructure or the introduction of policies.

An example of WIM and permit data fusion is presented for a TDM which collects network, traffic, and infrastructure data to determine the actual damage caused by heavy traffic. The TDM uses GIS network data, Weigh-in-Motion, and permit traffic data, as well as public domain data about bridges and pavements for infrastructure damage assessment. The model allows assessment of the wear and tear, and it advances the current state of knowledge by developing data-driven systems. **Figure 8** presents a concept of Transport Demand Model, which utilizes traffic data (WIM and permit) as well as infrastructure data with detailed information about the bridge and pavement types and its condition. In the US, the public domain data provided through InfoBridge and InfoPave data through FHWA allow for a combination of infrastructure data with a GIS system. Permit data can be used to determine heavy corridors, so determine roads and bridges utilized by the overloaded traffic and then match with the existing infrastructure. Traffic and infrastructure data combined in the GIS system provide a basis to determine damage based on vehicle characteristics and infrastructure parameters.

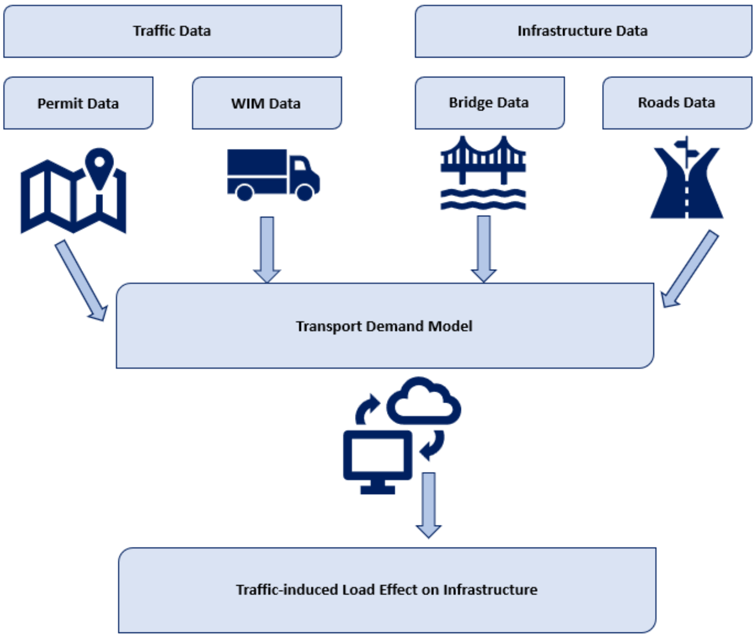


Figure 8 – Fusion of data by using Transport Demand Model.

8. Summary and Conclusions

Heavy permit traffic significantly contributes to the damage caused to roads and bridges. Therefore, the size and weight regulations were developed along with the permit fee schedule to control heavy traffic operations, maintain the good condition of infrastructure, recover damage costs, and provide a possibility for efficient and economically justified transport. Recent data shows that permit traffic is growing, but the damage caused to roads and bridges has not been quantified. The development of the damage assessment model is necessary to control the operation of permit traffic and improve enforcement and safety.

Traffic data provide opportunities to assess and develop advanced models to predict the impact on structures. An improved understanding of long-term structural behavior through data assessment can help quantify the damage. Traffic weight data can support the development of design and evaluation methods to efficiently set strategies for maintenance, repair, and rehabilitation.

Massive traffic data is gaining immense importance in traffic analysis, and it can be used to better understand the impact of the traffic weights on infrastructure. Therefore, there is a need to promote data-driven management systems to enhance safety and reliability. Transport demand models can be utilized to store, and process data on road infrastructure, including pavements and bridges, regular traffic, and permit vehicle operations.

Moreover, the availability of permit and WIM data creates new opportunities for heavy traffic analyses and research. The recorded data results in advanced knowledge of freight trip characteristics and a possibility of improvement of safety and longevity of structures to ensure the safety and efficiency of transportation operations.

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