Enforcement and Compliance Comparative Analysis

Comprehensive Truck Size and Weight Limits Study

MAP-21
Section 32801

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Desk Scan

Final Draft

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CHAPTER 1 - INTRODUCTION TO THIS REPORT

This report documents and summarizes the findings from the literature review of prior work completed in the area of truck size and weight enforcement and compliance. The findings support subsequent work concerning truck size and weight enforcement costs and effectiveness, which are required by under the MAP-21 Section 32801 *Comprehensive Truck Size and Weight (CTSW) Limits Study.*

The purpose of the literature review is to objectively summarize available information on truck size and weight enforcement from around the world, on a document-by-document basis. The summaries are organized by topic and presented in reverse chronological order (from most recent to oldest). No synthesis or interpretation is included as part of this report. The review focuses on:

- Needs and traditional approaches for truck size and weight enforcement, and the impacts of regulatory changes on enforcement programs (Chapter 2);
- Enforcement costs (Chapter 3);
- Enforcement benefits (Chapter 4);
- The effectiveness of truck size and weight enforcement (Chapter 5);
- The application and performance of truck size and weight enforcement and compliance technologies (Chapter 6); and
- Alternative approaches for achieving compliance (Chapter 7).

The review emphasizes the enforcement of truck size and weight limits; however, distinguishing enforcement activities concerning truck size and weight from those directed at safety or credentials regulations is not always possible. Therefore, the review includes findings relevant to the general task of enforcing truck operations when they are also applicable to the enforcement of truck size and weight limits.

The review involves a comprehensive search of relevant literature published in the last decade (since around 2000) worldwide, plus key historical material. The principal aim of the search is to gain a thorough understanding of the current state of research and practice concerning truck size and weight enforcement and compliance. The literature search includes three information sources: (1) engineering and scientific periodicals and journals; (2) conference proceedings; and (3) readily-available government and industry reports. Specific resources include:

- Transportation Research International Documentation (TRID)
- American Society of Civil Engineers
- University of Michigan Transportation Research Institute Library
- University of Manitoba Transport Information Group Library
- ScienceDirect
- NRC Research Press
- Transportation Association of Canada
- Heavy Vehicle Transport Technology Proceedings
- Federal Highway Administration (FHWA) library
- American Transportation Research Institute library
- National Transport Commission (Australia) library
- Australian Road Research Board library

The search supplements the following key historical material:

- *Comprehensive Truck Size and Weight Study* by the U.S. Department of Transportation, 2000 (2000 CTSW Study)
- Relevant special reports by the Transportation Research Board, namely *Special Report 267 Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles* and *Special Report 225 Truck Weight Limits: Issues and Options*
- Recent truck size and weight reports conducted in Maine, Vermont, Wisconsin, and Minnesota
- *Moving Freight With Better Trucks* by the International Transport Forum
- NCHRP Web Document 13 entitled *Developing Measures of Effectiveness for Truck Weight Enforcement Activities*
- *National Heavy Vehicle Enforcement Strategy Proposal* by the National Transport Commission (Australia)

CHAPTER 2 - ENFORCEMENT NEEDS AND APPROACHES (INCLUDING IMPACTS OF CHANGES)

2.1 Needs (Extent of the Problem)

Table 1 summarizes the findings from Section 2.1 that are most relevant to the current research effort.

Table 1. Key Documents Summary for Section 2.1

Key document	Contributions to current research effort
FHWA 2012	• Provides recent indication of weight non-compliance within the context of a purposely designed pilot program • Establishes indirect linkage between weight non-compliance and safety
Siekmann and Capps 2012	• Finds that, of the 1,873 Level 1 inspections performed on overweight vehicles in 18 states over a six-month period in 2012, a vehicle out-of-service (OOS) violation was found on 44.79 percent of the vehicles; this rate is higher than the 2011 national OOS rate of 27.23 percent • Finds that overweight trucks are more likely to be overweight on an axle rather than to exceed the gross vehicle weight limit, with an average amount of weight over the legal axle limit of about 2,000 pounds
Ramseyer *et al.* 2008	• Provides results of a survey of states concerning enforcement programs and compliance experience • Finds that in, a majority of states (23 of 28), intrastate trucks are more frequently overloaded than interstate trucks • Finds that, in a majority of states (14 of 26), trucks

Key document	Contributions to current research effort
	carrying bulk material were most frequently overloaded
Straus and Semmens 2006	• Estimates the cost of overweight trucking on Arizona highways, based on a series of analytical assumptions • Indicates that enforcement targeting may have a significant impact on proportion of trucks measured as overweight • Finds that overweight trucking varies in time and space • Finds that Class 9 trucks have the highest rate of in-state overweight violations
URS 2005	• Identifies key issues concerning enforcement, including: scale by-passing; declining enforcement resources; need for performance-based programming; inability to measure compliance; need for adoption of technologies; limited capability of traditional enforcement methods
TRB 2002	• States that estimates of overweight trucks are fragmentary and inconsistent • Indicates that overweight trucking is concentrated on the bulk hauling segment of the industry
TRB 1990	• States that reliable estimates of overweight trucking are unavailable

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding enforcement needs (extent of the problem):

- The Federal Highway Administration (FHWA) (2012a, pp. 21-22) investigates enforcement levels and overweight axles as a potential contributor to truck crashes as part of the Vermont pilot program. This program saw an increase in truck size and weight limits on Vermont’s Interstate System highways for a one-year period, including allowance of a 6-axle tractor semitrailer limited to 99,000 lb. gross vehicle weight (GVW). The report indicates that, on average in Vermont, three percent of single axles exceed the 20,000-lb. limit and 13 percent of tandem axles exceed the 36,000-lb. limit in effect during the pilot program. The overweight observations may or may not involve pilot vehicles or vehicles operating under permit. In addition, an analysis of crash data reveals that approximately half the carriers involved in the pilot program were involved in crashes during the program, though these crashes may not have involved pilot program trucks.

- Siekmann and Capps (2012, p. 19) provide interim findings to Federal Motor Carrier Safety Administration (FMCSA) concerning heavy and overweight vehicle defects. Based on data obtained about overweight trucks from nationwide data collection effort facilitated by the Commercial Vehicle Safety Alliance (CVSA) and an additional, smaller but more detailed dataset, the authors conclude the following:

- Of the 1,873 Level 1 inspections performed on overweight vehicles in 18 states over a six-month period in 2012, a vehicle out-of-service (OOS) violation was found on 44.79 percent of the vehicles. This rate is higher than the 2011 national OOS rate of 27.23 percent.
- Brake-related defects were the main reason for a vehicle being placed OOS, "with approximately 30 percent of all vehicles having an OOS brake violation". Properly working brakes are "important in order to reduce the potential for crashes".
- Overweight trucks are more likely to be overweight on an axle rather than to exceed the gross vehicle weight limit, with an average amount of weight over the legal axle limit of about 2,000 pounds.

The authors conclude that "it may not be safe to assume that a vehicle found to be overweight as part of this data collection effort is overweight on every load they haul, but it can be inferred that vehicles that tend to be overweight occasionally are lacking proper vehicle maintenance".

- Ramseyer *et al.* (2008, pp. 31-53) conducted a survey of all 48 contiguous states concerning enforcement and compliance with 38 states providing responses (although not every question was answered by each respondent). The survey results provide useful information about truck weights and overloading.

  The survey finds the following:
  - Five of 12 responding states report that less than five percent of weighed trucks are overloaded (p.31).
  - Three of 12 states reported overloaded rates between five and 20 percent (p.31).
  - Two of 12 responding states report more than 20 percent of weighed trucks are overloaded (p.31).
  - 38 of 38 respondents indicated they use mobile enforcement (p.35).
  - 31 of 38 respondents indicated they have weigh-in-motion (WIM) systems (p.41).
  - 16 of 29 respondents indicated they use virtual enforcement (which normally involves a WIM and an image capture system); 13 do not, and nine did not respond (p.44).
  - 21 of 26 respondents indicated they use an electronic by-pass system (which normally involves a WIM and other vehicle identification technologies placed in advance of a fixed weigh scale); 5 do not and 12 did not respond (p.45).
  - 15 of 35 respondents indicated that weight compliance has increased due to implementing the Commercial Vehicle Information Exchange Window (CVIEW) or Commercial Vehicle Information Systems and Networks (CVISN); four indicated that compliance has not improved and 16 were undecided (p.49).
  - 23 of 28 respondents indicated that intrastate trucks are overloaded more frequently than interstate trucks; two indicated that overweight trucks were equally distributed between intrastate and interstate trucks; and three indicated that interstate trucks are more frequently overloaded than intrastate (p.50).

  - 14 of 26 respondents indicated that trucks with bulk material were most frequently overloaded; four indicated trucks with construction or commercial material were most frequently overloaded; and eight indicated that all types of trucks were equally likely to be overweight (p.53).

- Straus and Semmens (2006, pp. 24-25, 55-58), in a report prepared for the Arizona Department of Transportation (DOT), estimate the cost of overweight vehicle travel on Arizona highways. As a basis for the range of estimates presented, the authors use cost figures attributed to all commercial vehicles from Arizona's highway cost allocation model and the proportion of federal estimates of nationwide pavement maintenance costs allocated to Arizona. These figures indicate that commercial vehicles (including overweight trucks) in Arizona range between $210 million and $420 million per year. From this starting point, the authors factor in costs specifically attributed to overweight trucks (based on an estimate that 15 percent of trucks operate overweight), the disproportionate damage caused by heavier axles, and revenues generated by heavy vehicle travel. The authors conclude that "overweight vehicles impose somewhere between $12 million and $53 million per year in uncompensated damages to Arizona highways." Arizona DOT spends nearly $6 million on mobile enforcement activities, which are in part directed at deterring overweight trucking. Thus, if doubling the budget for mobile enforcement was "50 percent effective toward the objective of eliminating illegally overweight vehicles," annual pavement damage savings would range from $6 million to $27 million. These figures translate into a range of benefit-cost ratios between one and four or five.

  To support the foregoing analytical work, the authors provide results from a survey of 25 states concerning their experiences with truck weight enforcement and overweight trucking. Responses indicate a wide-range of estimates (between 0.5 and 30 percent) as to the proportion of vehicle travel that is overweight in the surveyed states. Only five states provided an estimate of the costs attributed to this travel, though the credibility of these estimates is questionable. In addition, the survey revealed the following insights:
  - Of the vehicles weighed using mobile enforcement the percentage of vehicles exceeding legal limits ranged from less than one percent to nearly 100 percent in the surveyed states. This range likely reflects the presence of targeting strategies. Of the overweight vehicles (where data are available), the average number of pounds overweight (on the whole vehicle) ranged between 2,000 and 10,000 lbs.
  - Locations and times where overweight violations occur supports the notion of increasing resources on state roads during "after hours" times.
  - Of the various vehicle classes, class 9 vehicles have the highest rate of in-state overweight violations.

- Rooke *et al.* (2006, p. 25) estimate the cost of damage to infrastructure by overloaded vehicles for the European Union's (EU) project REMOVE which seeks to provide a framework for weigh-in-motion (WIM) systems to reduce danger and damage caused by overweight vehicles. Due to limited research the term infrastructure refers only to roadways. The estimated cost of damage incurred from overloaded vehicles is composed of the cost of road maintenance and the corresponding cost of traffic delays caused by road maintenance. Using the Netherlands data to estimate damage costs and assuming the same percentages hold for the other 14 EU countries, the authors reason that the EU spends from €239 million to €557 million on repairing road damage caused by overloaded vehicles. Considering only the national road networks the cost ranges from €153 million to €227 million. For comparison, the road maintenance budget of the 15 EU countries combined is €10,500 million. The authors conclude that the "possible level of damage to the infrastructure caused by overloaded vehicles is significant." As well, the potential savings from using correctly loaded goods vehicles is significant. They recommend member states set targets to "reduce maintenance budgets by effective compliance strategies for overloaded vehicles."

- URS (2005) identifies the following key issues concerning enforcement, which can be interpreted as needs and areas that enforcement programs should address:
  - By-passing of fixed weigh stations (p.33)
  - Declining enforcement resources and/or fixed resources with increasing truck volumes (p.33)
  - Enforcement programs should be performance-based and performance measures should guide decision-makers (p.33)
  - Inability to measure compliance (p.33)
  - Apparent ineffectiveness of fixed weigh scales for weight enforcement shortly after the scale opens (p.39)
  - Potential for portable scales to be used on lower volume highways (p.52)
  - Potential for using WIM devices as weight enforcement tools rather than exclusively for planning purposes
  - Importance of WIM maintenance and accuracy and the required resources to maintain adequately operating WIMs
  - Traditional enforcement approaches do not provide field inspectors with a method of determining if an overweight vehicle has a permit prior to pulling the vehicle over (p.41)
  - There is a need and an opportunity to establish and refine practical performance measures for weight enforcement that are effective and affordable (p.42)
- The Transportation Research Board (TRB) (2002, pp. 171-172) states that estimates of operating weights of trucks are "fragmentary and inconsistent." According to state officials, overloading problems appear to be concentrated in certain industry segments which haul bulk, high density (*i.e.,* weigh-out) commodities. The authors cite estimates of actual non-compliance made by four independent studies.
  - Grenzeback *et al.* (1988) "estimate that 15 percent of large trucks would exceed axle weight or gross vehicle weight limits on a segment of Interstate highway where enforcement was not taking place." This study also suggests that a "minimum" violation rate of six percent exists at fixed scales.
  - A study by the FHWA (1993) indicates that "only 0.6 percent of trucks exceed gross vehicle weight limits at weigh stations." This number is affected by overweight trucks that "routinely avoid the stations."

- Hajek and Selsneva (2000) estimate that 12 percent of tandem axles exceeded the federal (U.S.) maximum of 34,000 lbs., according to data collected at several hundred WIM sites.
- Unpublished U.S. Department of Transportation (USDOT) estimates attribute “10 percent of all miles of travel by trucks with three or more axles to vehicles weighing more than 80,000 lbs.” This includes both legal and illegal overload operations. No information is provided in the report about when these data were collected.

- TRB (1990, p. 141) cites earlier work concerning the extent of overweight trucking activity. The report finds that “reliable estimates of the magnitude and frequency of illegal overloads are not available.” Available WIM data collected in six states between 1984 and 1986 reveals that “about 10 to 20 percent of all combinations are operating illegally overweight without a permit.” A survey of truck weight enforcement personnel corroborates this finding by suggesting that “more than 10 percent but less than 25 percent of trucks are overloaded.”

2.2 Traditional Approaches

Table 2 summarizes the findings from Section 2.2 that are most relevant to the current research effort.

Table 2. Key Documents Summary for Section 2.2

Key document	Contributions to current research effort
Carson 2011	• Lists the general components of traditional truck size and weight enforcement programs, based on a synthesis of literature
OECD 2011	• Lists the general components of traditional truck size and weight enforcement programs, based on an international study
Allen 2002	• Identifies principles for establishing a targeted weight enforcement program
TRB 2002	• Differentiates between fixed and portable weight enforcement methods and the special requirements of enforcing oversize/overweight loads
USDOT 2000	• Lists the general components of traditional truck size and weight enforcement programs

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding traditional enforcement approaches:

- Carson (2011, p. 37), in a compilation of significant truck size and weight research as part of National Cooperative Highway Research Program (NCHRP) 20-07 Task 303, summarizes literature concerning truck size and weight enforcement practices and effectiveness. The author lists the following as components of truck size and weight enforcement programs: static scales and weigh station personnel; portable/semi-portable scales and mobile personnel; WIM and automatic vehicle classification (AVC) equipment; fines, penalties, and sanctions; the judicial system; and industry self-certification. In the U.S., these elements and enforcement-related research has been principally directed at enforcing truck weight rather than truck dimensions.
- The Organisation for Economic Cooperation and Development (OECD) (2011, p. 281) indicates that traditional approaches to truck size and weight enforcement involve direct, on-road observation of non-compliance undertaken by enforcement officers. These observations typically occur at permanent (fixed) weigh scales or in mobile patrol cars. These activities may be supplemented by operator risk profiles that, when delivered to officers via appropriate information systems, may enhance the effectiveness of size and weight enforcement efforts (though the risk profiles are normally focused on safety ratings).
- Cambridge Systematics (2009c, pp. 1-10) identifies fixed weigh scales, WIM, and patrol officers equipped with portable weigh scales as the main components of Wisconsin's truck size and weight enforcement program. Fixed equipment is concentrated on highly trafficked routes while enforcement of secondary and rural roads is largely conducted by mobile officers.
- Cambridge Systematics (2006, p. B-17) indicates that truck size and weight enforcement in Minnesota occurs through roadside inspections using portable scales and at fixed weigh stations.
- Allen (2002, pp. 177, 180) provides two principles governing targeted truck size and weight enforcement. First, the entire population of heavy vehicles should be monitored to control the system and provide the range of compliance rates within the industry. This enables a regulator to identify current and future outliers within a dynamic industry. Second, targeted enforcement should identify and capture high-risk offenders that fall outside established regulatory limits. This principle relies on appropriate processes to remove offenders from the industry or bring their behaviour back into accepted norms.

  The author also states that visible mobile enforcement, when supported by portable computing equipment to enable real-time data input and extraction, "can deliver a significant level of behavioural change at a high benefit/cost ratio."
- TRB (2002, p. 170) indicates that state truck size and weight enforcement has traditionally involved weighing trucks at fixed weigh stations and using portable scales. The enforcement of dimensional limits has seen less emphasis. Specially-permitted oversize and overweight vehicles require particular attention within state enforcement programs.
- USDOT (2000, p. VII-7) identifies the following elements of a fixed weigh scale: stationary scales, space and lighting for inspections, communications equipment,

signage, shelter and washroom facilities, acceleration/deceleration lanes, and technologies such as WIM, automatic vehicle identification (AVI), and cameras.

2.3 Impacts of Regulatory Changes

Table 3 summarizes the findings from Section 2.3 that are most relevant to the current research effort.

Table 3. Key Documents Summary for Section 2.3

Key document	**Contributions to current research effort**
Carson 2011	• Emphasizes the need for uniformity of truck size and weight regulations to improve enforcement effectiveness
Cambridge Systematics 2009c	• Identifies the need for additional inspection personnel (in Wisconsin) should truck size and weight laws change
Cambridge Systematics 2006	• Indicates that a complex regulatory structure complicates compliance
Quinlan 2002	• Finds that fragmented approaches lead to non-compliance
TRB 2002	• Suggests that complex regulations and numerous exceptions (*e.g.,* special permits) challenge enforceability of regulations • Technological applications may facilitate enforcement of complex regulations

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding the impacts of regulatory changes:

- Carson (2011, p. 38), in a compilation of significant truck size and weight research as part of NCHRP 20-07 Task 303, summarizes literature concerning truck size and weight enforcement practices and effectiveness. The author asserts that truck size and weight regulations "should be uniform in their scope and relatively simple to comprehend, apply, and enforce." Regulations that are too complex or which contain numerous exceptions lead to lower levels of enforcement and prosecution.
- Cambridge Systematics (2009c, p. ES-17) suggests that Wisconsin may need additional enforcement resources (particularly inspection personnel) should changes occur to Wisconsin's truck size and weight laws.
- Cambridge Systematics (2006, p. 20) reports findings concerning truck size and weight enforcement from public outreach conducted as part of Minnesota's truck size and weight study. The findings indicate that the complexity of Minnesota's truck size and weight laws "complicate compliance"; simplification and education are required.
- Quinlan (2002, p. 242) indicates that a coordinated and targeted compliance approach in the road transport industry is needed to overcome fragmented regulatory approaches.

Fragmented approaches are "unfair, inconsistent, confusing […] and offer too many avenues for calculated evasion."

- TRB (2002, pp. 171, 173-174) suggests that a lack of sufficient enforcement impedes the effectiveness of truck size and weight regulatory reform. Regulatory complexity or the introduction of trucks that may be easier to overload are examples of enforceability problems that may occur due to reforms. Similar problems may result from permit programs or exceptions that continue to grow and become more complex, particularly since data about the number of legal permitted loads operating in excess of 80,000 lbs. and the distance these loads travel are limited. The report suggests (p. 179) that technology applications could "greatly facilitate" the administration and enforcement of more complex truck size and weight regulations, permit programs, certification programs, and performance-based regulatory approaches.

CHAPTER 3 - ENFORCEMENT COSTS

Table 4 summarizes the findings from Chapter 3 that are most relevant to the current research effort.

Table 4. Key Documents Summary for Chapter 3

Key document	Contributions to current research effort
NTC 2009	• Calculates costs (to the enforcement agency) and benefits over a five-year period associated with the implementation of the National Heavy Vehicle Enforcement Strategy (Australia) under three benefits scenarios (low, medium, high) which assume varying levels of crash reduction, reduced road damage, and improved enforcement efficiencies • Determines benefit-cost ratios for the strategy ranging between 4 to 1 and 20 to 1
Rooke *et al.* 2006	• Estimates enforcement costs (to the enforcement agency) for: (1) manual selection of overloaded vehicles; (2) using WIM for pre-selection; an d (3) using WIM for direct enforcement • Using WIM for direct enforcement costs € 3 per year per overloaded vehicle, compared to € 75 per year per overloaded vehicle for the WIM for pre-selection scenario and € 145 per year per overloaded vehicle for the manual selection case
Straus and Semmens 2006	• Finds, based on a survey of 25 states, that the average annual budget for a state mobile enforcement unit is $3.7 million
URS 2005	• Reports that 100 WIM sites could be installed for the same cost as the construction of one fixed weigh scale

	• Indicates that the annual operating costs of 100 WIM sites is about one-quarter the annual operating cost of one fixed weigh scale
USDOT 2000	• Indicates that trucks with more axles take more time to weigh

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding enforcement costs:

- Australia's National Transport Commission (2009, pp. ES-1, 2) estimates the costs and benefits over a five-year period of the National Heavy Vehicle Enforcement Strategy which was proposed in 2007 (National Transport Commission, 2007). This strategy aimed to promote consistent, effective and efficient enforcement in heavy vehicle transport law in Australia. In particular, the strategy focused on increased use of intelligence-driven enforcement and coordinating practices between Australian states as they implement reforms such as the chain of responsibility principle.

  The main costs associated with implementation of the strategy relate to the collection and analysis of data and the establishment of national coordination practices. In total, costs to the enforcement agency (in 2008 Australian dollars) summed to $2.6 million in year one and rose to $3.1 million per year thereafter. Benefits gained by more targeted enforcement included heavy vehicle crash reduction, reduced road damage from overloading, and improved enforcement cost efficiencies. Since considerable uncertainty exists when estimating benefits, three benefit scenarios (low, medium, high) were developed as part of the estimation process. Based on available data and experience, the low benefit scenario assumed a one percent reduction in heavy vehicle crashes, a one percent reduction in road damage, and a one percent improvement in enforcement efficiency. The medium and high benefit scenarios were calculated based on three and five percent improvements in these areas, respectively. Under these scenarios, in 2008 Australian dollars, the following annual benefits were calculated: (1) between $13 million and $65 million for reduced heavy vehicle crash costs; (2) between $0.6 million and $2.8 million for reduced road wear; and (3) between $1.2 million and $6 million for improved enforcement efficiency. In terms of net present value over the five-year period (using a four percent discount rate); the strategy would see a net benefit ranging from $38 million to $246 million, corresponding to a benefit-cost ratio of between 4 to 1 and 20 to 1. Even a 50 percent increase in costs would see net benefits and benefit-cost ratios between 2.6 to 1 and 13 to 1.

- Rooke *et al.* (2006, p. 21) evaluate the cost of enforcement activities for the European Union's project REMOVE which seeks to provide a framework for WIM systems to reduce danger and damage caused by overweight vehicles. The authors determine enforcement costs (shown in **Table 5**) for three enforcement scenarios: (1) manual selection; (2) WIM for pre-selection; and (3) WIM for direct enforcement. These figures assume that the number of overloaded vehicles remains the same regardless of the enforcement scenario and that WIMs used for direct enforcement require a higher level of accuracy then those used for pre-selection.

Table 5. Costs to the Enforcement Agency by Enforcement Scenario

Scenario	Enforcement cost per year	Enforcement cost per year per officer	Enforcement cost per year per overloaded vehicle
Manual selection	€ 160,000	€ 53,333	€ 145
WIM for pre-selection	€ 422,500	€ 70,417	€ 75
WIM for direct enforcement	€ 322,150	-	€ 3

- Straus and Semmens (2006, pp. 31-45), in a report prepared for the Arizona DOT, provide results from a survey of 25 states concerning their experiences with truck weight enforcement and overweight trucking. The survey reveals that mobile enforcement is useful for detecting and deterring overweight vehicle travel. Responses indicate a wide range of commitment to mobile enforcement programs in terms of budgets, person-hours assigned to this duty, and the number of vehicles weighed. On average, the budget for a state mobile enforcement unit was $3.7 million annually.
- URS (2005, p. 49) estimate and compare enforcement costs for fixed weigh scales and virtual WIM enforcement stations. They find that approximately 100 WIM sites could be built for the cost of one fixed scale site (assumes $15 million for fixed site construction and $150,000 for a WIM site) and the annual operating costs for 100 WIM sites is about one-quarter of the annual cost of one fixed site.
- USDOT (2000, p. VII-7) indicates that trucks with more axles require more time to weigh. The report indicates that in Michigan, as an example, it takes two hours to weigh an 11-axle combination truck using portable scales.

CHAPTER 4 - ENFORCEMENT BENEFITS

Table 6 summarizes the findings from Chapter 4 that are most relevant to the current research effort.

Table 6. Key Documents Summary for Chapter 4

Key document	Contributions to current research effort
URS 2013	• Estimates, based on data from a virtual WIM, pavement preservation savings of $850,000 per year on Indiana's highway network with the implementation of a comprehensive compliance program
FHWA 2012	• Describes preliminary findings from the Maine and Vermont pilot program that allows for gross vehicle and axle weights on the Interstate System beyond normal federal limits • Finds that increased vehicle loadings would cause

Key document	Contributions to current research effort
	additional pavement damage which could be limited through industry cooperation and increased enforcement
Honefanger *et al.* 2007	• Notes that the benefits from enforcement technologies have not been "precisely quantified" • States that the most frequently quantified benefit relates to enforcement efficiency, calculated as the number of overweight citations per total trucks inspected
Santero 2005	• Concludes that targeted implementation of Virtual Weigh Stations (VWS) would yield pavement life benefits
Stephens *et al.* 2003	• Utilizes WIM data to direct mobile enforcement resources, which resulted in a reduction of pavement damage caused by overweight vehicles
TRB 2002	• Suggests that effective adoption of enforcement technologies has the potential for reducing enforcement program costs regardless of whether truck size and weight regulatory changes occur • Indicates that rigorous enforcement could increase overall distance travelled by large trucks, which could be seen as a cost to shippers larger than the incremental pavement damage costs caused by overloading
Taylor *et al.* 2000	• States that the best overall enforcement program includes a combination of fixed and mobile weight enforcement activities

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding enforcement benefits:

- URS (2013, p. ii) develops a business plan for Indiana's truck weight compliance program. The report cites proven performance of a pilot virtual WIM site in the state. Based on data collected at this state, the report estimates that a "conservative minimum estimate of $850,000 per year in pavement preservation can be saved across the state network with a comprehensive compliance program". This estimate could range as high as $3 million per year (or even higher). The report also estimates that the cost of a virtual WIM installation would be recovered by the enforcement agency through pavement damage reduction in three to six years.

- FHWA (2012b, pp. 2-3), in a 6-month report on the Maine and Vermont pilot program, describes preliminary findings of the program with a focus on bridge and pavement impacts. The program allows for gross vehicle and axle weights on the Interstate System beyond normal federal limits. In Maine, the program enables operation of six-axle tractor semitrailers up to 100,000 lbs. and tandem axle weights up to 46,000 lbs. for certain commodities. In Vermont, the program enables operation of six-axle tractor semitrailers up to 99,000 lbs. and tandem axle weights up to 39,600 lbs. (inclusive of a

10 percent weight tolerance). The report does not make direct reference to enforcement issues, but does mention the need for increased monitoring of bridges using WIM devices. Regarding pavements, the increased vehicle loadings would cause additional pavement damage which could be limited through industry cooperation and increased enforcement; no details are provided as to the extent of benefit that may be gained by industry cooperation and increased enforcement. Conclusive findings are expected after the full implementation of the program.

- Honefanger *et al.* (2007, p. 3) evaluate procedures used for commercial vehicle size and weight enforcement in six European countries as part of the FHWA-PL-07-002 report. They note that benefits from enforcement technologies currently used are not yet "precisely quantified." The most common quantified benefit relates to enforcement efficiency calculated as the number of overweight citations per total trucks inspected.
- Santero (2005, p. 15) analyzes the effects of overweight trucks on California highways and the potential benefit of implementing virtual weigh stations (VWS). The author finds that 5.74 percent of pavement damage on the California highway network is directly associated with overweight trucks that represent fewer than 2.67 percent of the axles measured. Damage is calculated using equivalent single axle loads (ESALs) that increase exponentially with vehicle weight. This results in overweight trucks being disproportionately large contributors to pavement damage. They conclude that if VWS were installed at the top ten existing WIM sites, of the 131 total WIM sites in the state, the average pavement life saved across those sites would be 10.71 percent. The report assumes that "when installed, a VWS is 100 percent effective in deterring overweight vehicles" (p. 9) and that the WIM database is representative of the entire state network.
- Stephens *et al.* (2003, pp. 143-148) use WIM data to determine the pavement damage caused by overweight vehicles each month, identify the vehicle configurations contributing the most to pavement damage, and their time and direction of travel. This information was used to deploy officers to the top five sites in terms of damage caused by overweight trucks. In the subsequent year of targeted enforcement using this information, pavement damage from overweight vehicles decreased by 4.8 million ESAL-miles (approximately $500,000 in savings) and the number of overweight vehicles at the WIM locations decreased by 20 percent (p.143). Due to the short timeframe of the program (*i.e.*, one year to identify the top five locations and one year to target enforcement) the authors caution the extrapolation of these results to long-term horizons and acknowledge that there are year-to-year changes in overweight vehicle operations irrespective of enforcement activity (p.147). The authors find that there were increases in overweight vehicles at other enforcement sites that had lower enforcement activity due to shifting resources based on WIM information; however, these were generally low-volume sites (p.148).
- TRB (2002, p. 183) suggests that effective adoption of enforcement technologies has the potential to induce "substantial cost reductions" for enforcement programs, regardless of whether changes to truck size and weight limits occur. These technologies and the information systems supporting them will also enable research and evaluation efforts that lead to a fuller understanding of the benefits of effective enforcement.

More specifically, citing TRB (1990), TRB (2002, p. 174) indicates that if no change in the quantity of truck freight occurred, the elimination of illegal overloads could reduce pavement costs by $160 million to $670 million per year in the United States. Further, “rigorous enforcement” would cause a 0.5 to 2.5 percent increase in annual vehicle miles travelled by large trucks, corresponding to an annual cost to shippers of $500 million to $2.5 billion. These figures may encourage shippers to “pay the added pavement costs generated by their overloaded trucks instead of reducing their loads.”

- Taylor *et al.* (2000, p. 241) reference a model developed by researchers in Idaho which predicts that a continuously operated weigh scale with an area coverage of 160 miles would prevent approximately $46 million in pavement damage over the life of the pavement. Further, the authors indicate that a combination of fixed and roving enforcement facilities provides the best overall weight enforcement program.

CHAPTER 5 - EFFECTIVENESS OF ENFORCEMENT

Table 7 summarizes the findings from Chapter 5 that are most relevant to the current research effort.

Table 7. Key Documents Summary for Chapter 5

Key document	Contributions to current research effort
URS 2013	• Provides recommendations to improve the effectiveness of Indiana’s truck weight compliance program, including increasing resources to fixed scales, expanding functionality of existing databases, upgrading WIM sites to virtual WIM sites, and changing the permit fee structure
Carson 2011	• Concludes that a lack of reliable evidence concerning overweight trucking and disparate enforcement practices across the United States preclude definitive understanding of the relationship between enforcement activities and truck size and weight compliance • Reports on the effectiveness of enforcement as evidenced by the following violations rates (based on available literature): (1) 1 percent at fixed weigh scales; (2) 15 percent when no enforcement is present; and (3) 30 percent on scale bypass routes • States that enforcement programs that combine fixed and mobile activities are “most effective in ensuring truck size and weight compliance” • Indicates that technological implementation broadens the temporal and geographic coverage of enforcement beyond the capabilities of traditional fixed and roving enforcement • States that on-road enforcement effectiveness may be impeded by realities within the judicial system
OECD 2011	• Indicates the potential use of WIM for determining the compliance record of specific higher capacity vehicle configurations
Regehr *et al.* 2010	• Assesses weight compliance of Rocky Mountain doubles, Turnpike

Key document	Contributions to current research effort
	doubles, and triples operating in the Canadian Prairie Region using WIM data • Reports compliance rates of 99 percent for gross vehicle weight and all axle groups except steering axles
Cambridge Systematics 2009c	• Indicates that current enforcement levels and low fines provide an "incentive for noncompliance"
Honefanger *et al.* 2007	• Cites experience in the Netherlands where pre-selection using WIM improved officer efficiency from 40 to 80 percent (citations issued relative to vehicles stopped) • States that advisory notices are thought to be more effective than roadside inspections because a "single contact can reach companywide rather than a single driver"
Strathman and Theisen 2002	• Reports that, based on an Oregon study, five-axle combination trucks (including tractor semi-trailers and truck-trailer configurations) are "somewhat" more likely to exceed weight limits than other vehicle classes • Finds that operators participating in programs that offer benefits to compliant trucks are less likely to operate overweight
Thomas 2002	• Suggests that defining enforcement effectiveness will remain unresolved, as some parties favor increased enforcement while others favor emphasis on achieving compliance • Emphasizes the need to engage interested parties as fundamental to improving enforcement effectiveness
TRB 2002	• Reports that few evaluations have been conducted on the effectiveness of enforcement strategies in terms of the frequency and magnitude of weight violations • Recommends development of information systems to support compliance assessment, enforcement effectiveness and targeting, and program evaluation
Strathman 2001	• Finds that increasing enforcement or increasing fines have about the same effect in deterring overweight vehicles, but increasing fines is more cost-effective
Taylor *et al.* 2000	• Suggests that low violation rates at weigh scales on primary highways is indicative of an effective enforcement program rather than an indication that enforcement is not required
USDOT 2000	• Notes general improvement in the level of enforcement activity following requirements for states to develop enforcement plans and adoption of new technologies • Indicates that quantifying the degree of non-compliance remains difficult
Hanscom 1998	• States that the effect of truck weight enforcement is unknown • Develops and empirically validates measures of effectiveness for truck

Key document	Contributions to current research effort
	weight enforcement activities in an effort to identify quantifiable measures that reflect the goals of enforcement programs
TRB 1990	• Contends that effective enforcement requires weight regulations that are uniform and relatively simple to comprehend and apply, along with sufficiently high penalties • Identifies forced off-loading of overweight trucks as “one of the most effective methods of ensuring compliance by shippers and operators” • Identifies the disadvantage to honest truckers if illegal overloading persists

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding effectiveness of enforcement:

- URS (2013, pp. ii-vii) provides program recommendations as part of the development of a truck weight compliance business plan for Indiana. The plan recognizes the need for an outcome-driven decision-making course that: (1) addresses the needs of the freight transport industry; (2) helps minimize infrastructure damage; (3) addresses safety issues; (4) meets federal and state mandates regarding truck weight enforcement; and (5) supports the Moving Ahead for Progress in the 21st Century (MAP-21) transportation bill. In general, the aim of the plan is to reduce the infrastructure damage cost burden overall and shift the burden away from taxpayers through appropriate fine and permit structures. The report recommends:
    - Maintaining existing fixed scales and restoring functionality at one scale that had been decommissioned;
    - Expanding the functionality of the existing central database server;
    - Upgrading ten existing WIM sites to virtual WIM sites;
    - Strengthening coordination between agencies involved in truck weight compliance within the state;
    - Analyzing the impact of a recent regulatory change in Indiana which permits divisible loads up to 120,000 pounds;
    - Changing the current permit fee structure to one which reflects the damage caused by varying axle loads; and
    - Building fixed weigh scales in regions in the state where this infrastructure is currently lacking.
- Jones (2012, pp. 3-4) cites a case study in Tasmania to document the effectiveness of truck size and weight enforcement. In the case study, there was a noticeable increase in overweight truck operations upon suspension of enforcement. When enforcement was re-introduced, overweight violations were halved.
- Carson (2011, p. 38), in a compilation of significant truck size and weight research as part of NCHRP 20-07 Task 303, summarizes literature concerning truck size and weight enforcement practices and effectiveness. The author finds that there is a lack of reliable estimates on the extent of illegal truck size and weight activity available in published research. This, combined with disparate enforcement practices across the United States, "challenges the ability to accurately assess the direct relationship between enforcement activities and truck size and weight compliance." The literature that does exist (which is principally published prior to 2000) generally concludes that higher enforcement levels result in improved compliance. At fixed weigh scales on Interstate System highways, Carson reports a violation rate when enforcement is present of one percent, but a violation rate without enforcement of 15 percent. By-pass routes have violation rates of approximately 30 percent. Enforcement programs that combine fixed and mobile activities are "most effective in ensuring truck size and weight compliance," though these approaches have more recently been supplemented by greater implementation of technologies that broaden the temporal and geographic coverage of enforcement. The effectiveness of on-road enforcement efforts may be impeded by realities of the judicial

system, where misdirected or ineffective penalties may exist and misunderstanding about the impacts of truck overloading leads to low prioritization in the court system.

- OECD (2011, p. 298) states that WIM technologies have the potential to deliver more detailed, continuous data about weight compliance, specifically by utilizing axle spacing measurements to isolate the compliance record of higher capacity configurations.
- Regehr *et al.* (2010, pp. 8-9) assess regulatory compliance of three long truck configurations (Rocky Mountain doubles, Turnpike doubles, and triple trailer combinations) operating under special permit in the Canadian Prairie Region. The special permits contain vehicle, driver, operational, and network-related regulatory conditions. These vehicles are predominantly used to haul cubic (low density) freight. The authors use WIM data to assess compliance with (static) vehicle and axle weight regulations. The weight analysis, which was based on one year of (dynamic) weight data from a single WIM located on the Trans-Canada Highway, reveals that 99 percent (22,823 of 23,092) of Rocky Mountain doubles and Turnpike doubles comply with their static weight limit. Similarly, 99 percent of the dynamically measured single, tandem, and tridem axle weights were compliant with static weight limits. Steering axles were found to be compliant between 92 and 95 percent of the time.
- Cambridge Systematics (2009c, p. ES-10) report findings concerning truck size and weight enforcement from public outreach conducted as part of Wisconsin's truck size and weight study. The findings indicate that current enforcement levels and low fines provide an "incentive for noncompliance."
- Honefanger *et al.* (2007, p. 39) evaluate the procedures used for commercial vehicle size and weight enforcement in six European countries as part of the FHWA-PL-07-002 report. The Netherlands credit their pre-selection process with increasing officer efficiency from 40 percent to 80 percent (citations issued relative to vehicles stopped). Their pre-selection system includes piezoquartz WIM sensors in the two right-most lanes, two cameras on each side of the road to capture vehicle images, a camera above each lane to capture license plate numbers, and electronic loops and cameras in the third lane to capture bypassing vehicles.

  The Netherlands also utilizes the data collected from their pre-selection system to direct advisory notices of non-compliance to carriers consistently in violation of truck size and weight regulations. These advisory notices are thought to be more effective than roadside inspections because a "single contact can reach companywide rather than a single driver."
- Mattingly (2003, p. 16) surveys 29 U.S. states regarding the use of over height vehicle warning devices to reduce truck-bridge collisions. Eleven states use the technology. The author indicates that while laser and infrared systems seem "most effective" they are still susceptible to human error. As a result, a legislative solution may be more effective by increasing the penalties associated with these collisions beyond the current fines, which are often covered by an insurance company.
- Strathman and Theisen (2002, pp. vii-viii) collected WIM data from three sites near a weigh station on I-5; one site on I-5 and two sites on potential by-pass routes. Data were

collected prior to, during, and after an extended scale closure. The study finds that trucks did not appear to avoid the scale; further, trucks did not divert to I-5 during the scale closure (p. vii). The authors indicate that GVW on I-5 increased by 0.4 percent when the scale closed and decreased by 1.2 percent upon re-opening (these were statistically significant changes) (p. vii). The number of overweight vehicles (at a 95 percent confidence level) before closure was 2.27 percent, during closure was 3.67 percent (an increase of 61 percent), and after re-opening was 3.19 percent (decrease of 13 percent) (p. vii). The authors found that five-axle combination trucks (including tractor semi-trailers and truck-trailer configurations) were "somewhat" more likely to exceed weight limits compared to other vehicle classes during this case study (p. vii). Changes in weight for participants in the Green Light program (a transponder-based weigh station preclearance program) were minimal, suggesting that these operators were self-compliant or unwilling to risk losing their status and associated benefits (p. viii).

The study suggests that: (1) relatively aggressive enforcement in Oregon reduces the impact of increases in truck weight due to a single scale being shut down; (2) weight enforcement at a single site on I-5 which is a major interstate and international corridor may have little impact on interstate truck weights; and (3) operators participating in truck programs that offer benefits to compliant trucks are less likely to operate heavier trucks (p. viii).

- Taylor (2002, p. 136), provides an inspector's perspective on truck size and weight enforcement, and states that "without appropriate deterrence, many compliance strategies will simply fail."
- Thomas (2002, pp. 125, 129) asserts that the debate about what constitutes effective enforcement will remain unresolved. In essence, one side of this debate encompasses the view that more enforcers mean more enforcement, and more enforcement is more effective. The alternative view favors enforcement effectiveness gained through court-delivered sanctions, which should direct behaviours towards compliance. The authors suggests that "the most important key to effective enforcement is the engaging of all industry parties to play a more proactive role in managing all facets of their business operations to achieve compliance with their legislative obligations."
- TRB (2002, p. 175) reports that "few evaluations" have been conducted on the impact of enforcement strategies on the frequency and magnitude of weight violations. This lack of evidence stems from an absence of available data and the inability to implement statistically valid truck weight sampling plans. Recommendations to develop information systems to support compliance assessment, enforcement effectiveness and targeting, and program evaluation are evident in the literature since at least the early-1990s, namely from the TRB *Truck Weight Limits Study* (1990) and a report by the Office of Inspector General (1991).

  TRB (2002, p. 176) summarizes the proposed enforcement reforms made by the Office of Inspector General (OIG) Report (1991). This report recommended the following measures: (1) develop a program to produce the data needed to quantify the extent of overweight traffic; (2) require that states formulate annual enforcement plans and demonstrate the effect of enforcement on violations; (3) develop standards and technological improvements for WIM systems; (4) restrict state use of divisible-load permits and multiple-trip non-divisible load permits on the Interstate system; (5) evaluate fine structures; and (6) promote non-traditional enforcement techniques (such as the inspection of shipping and receiving logs for illegal loads).

- Strathman (2001, p. 7) conducts a purely economical and statistical analysis to develop linear regression models that relate enforcement intensity, fines, truck volume, and value per ton. The author finds that increasing enforcement or increasing fines have about the same effect in deterring overweight vehicles; however, the effect of enforcement is primarily attributed to roving scales. The author concludes that the most cost-effective way to reduce overweight vehicles is to increase fines since this has about the same effect as increasing enforcement levels but without the extra costs of enforcement.

- Taylor *et al.* (2000, pp. 237-238) suggest that low violation rates at weigh scales on primary highways is indicative of an effective enforcement program that deters overweight vehicles rather than an indication that enforcement is not required. The authors further suggest that accelerated infrastructure damage on secondary roads with less enforcement is an indication that increased enforcement is necessary. They reference studies performed by seven state agencies to conclude that overweight violation rates are around one percent for continuously operated (*i.e.*, high enforcement level) weigh stations on the U.S. Interstate System and between 12 and 34 percent for low enforcement level weigh stations (there is no definition for "low level").

  They also identify studies in Virginia and Idaho which found that up to 14 percent of truck traffic will use alternative routes to avoid weigh stations and that operators will travel up to 160 miles to avoid a weigh stations (p. 239). Virginia has found that trucks will purposely group together to exceed the ramp capacity of a weigh station, known as weigh station running or plugging. Overweight trucks travel at the rear of these groups and bypass the station when it has been temporarily closed. Virginia has found that more than 38 percent of trucks that were running by the station were found to be overweight (p. 239).

- In a review of federal truck size and weight enforcement programs, the USDOT (2000, pp. VII-4 to VII-6) notes a general improvement in the level of enforcement activity resulting from requirements for states to develop state enforcement plans (SEPs) and adoption of technologies such as WIMs for pre-screening. This increase in activity has been used to track enforcement effectiveness, principally in terms of the number of trucks weighed, the number of citations issued, violation rates, and requirements for vehicle offloading and load shifting. Quantifying the degree of non-compliance "continues to be difficult."

- Hanscom (1998, pp. 3, 7) states that "the effect of truck-weight enforcement programs is not known in terms of: (1) actual impacts on weight-law compliance, (2) effect on safety of truck operations, (3) pavement service life effects, or (4) cost-effectiveness of enforcement activity." Thus, Hanscom develops measures of effectiveness for truck weight enforcement activities. The focus of the research is to identify quantifiable measures that reflect the goals of an enforcement program (such as infrastructure protection) rather than using traditional indicators such as the number of trucks weighed, the number of violators detected, or the amount of fines collected. Initial development of candidate measures of effectiveness involved a survey of literature and state agencies, and the ranking of candidate measures in terms of: practicality of application, measurement reliability, support of statewide random sampling, absence of enforcement-induced bias, data collection methods capability, sensitivity to infrastructure damage, and applicability to data collection future technology. Candidate measures were then empirically validated using four independent field tests to determine the sensitivity of the measures to an imposed enforcement activity relative to baseline enforcement conditions. The validation revealed the weight enforcement measures of effectiveness defined below:

- "*Gross weight violation, proportion*: The fraction (or percentage) of the total observed truck sample which exceeds the legal gross weight limit.
- *Gross weight violation, severity*: The extent to which average measured gross weights for the observed sub-sample of gross weight violators exceeds the legal gross weight limit.
- *Single-axle weight violation, proportion*: The fraction (or percentage) of the total observed truck sample with one or more axles which exceeds the legal single-axle weight limit.
- *Single-axle weight violation, severity*: The extent to which average measured single-axle weights for the observed sub-sample of single-axle weight violators exceeds the applicable legal limit.
- *Tandem-axle weight violation, proportion*: The fraction (or percentage) of the total observed truck sample with one or more tandems which exceeds the legal tandem-axle weight limit.
- *Tandem-axle weight violation, severity*: The extent to which average measured tandem-axle weights for the observed sub-sample of tandem-axle weight violators exceeds the applicable legal limit.
- *Bridge formula violation, proportion*: The fraction (or percentage) of the total observed truck sample which exceeds the legal Bridge Formula weight.
- *Bridge formula violation, severity*: The extent to which average measured Bridge Formula weights for the observed sub-sample of Bridge Formula violators exceeds the legal weight.
- *Excess ESALs, proportion*: The fraction (or percentage) of the total observed truck sample exhibiting Excess ESALs; *i.e.,* ESALs attributable to the illegal portion of the individual single- or tandem-axle group.
- *Excess ESALs, severity*: The average value of Excess ESALs observed for the truck sub-sample exhibiting Excess ESALs."

Hanscom (p. 13) integrates these measures of effectiveness into a software tool which uses them as the basis for statistical comparisons between two enforcement conditions (*i.e.,* with and without enforcement activity). These comparisons can be made at a statewide/regional level, along a corridor, or at a specific location. The software also estimates pavement impacts.

- TRB (1990, pp. 135, 143) contends that to be "effective," the enforcement of weight regulations requires that they be uniform, relatively simple to comprehend and apply, and that penalties are sufficiently severe so as to deter non-compliance. The report also identifies forced off-loading of overweight trucks as "one of the most effective methods of ensuring compliance by shippers and operators."

  The report also observes that "because of the economic incentives for illegal overloading, honest truckers are at a disadvantage in competing for work with those who violate the law." From this perspective, any non-compliance would appear to be inappropriate—not so much because of its economic effect on infrastructure as from its implications for "the even playing field."

  The report recommends the following congressional actions to improve enforcement of truck weight laws: (1) direct federal funding of state enforcement; (2) imposition of federal penalties for violations of federal weight limits on Interstate highways, or alternatively, mandating of minimum state penalties; (3) federal provision for assessing penalties against parties for placing overweight shipments into commerce; (4) federal support for state measures to place overweight trucks out of service until they are offloaded; (5) development of educational programs for judges and prosecutors regarding the overweight problem; and (6) creation of a federally managed program for systematic collection of data on violators that would identify the responsible carrier or other operator so repeat offenders could be targeted.

CHAPTER 6 - APPLICATION AND PERFORMANCE OF ENFORCEMENT TECHNOLOGIES

Table 8 summarizes the findings from Chapter 6 that are most relevant to the current research effort.

Table 8. Key Documents Summary for Chapter 6

Key document	Contributions to current research effort
Intelligent Imaging Systems, Inc. 2013	• Finds the combined day and night read rate performance of a trailer/rear automated license plate recognition device was 43.75 percent and a hazardous material placard reader was 70.71 percent
CDM Smith (2012)	• Reviews multi-state weigh station pre-clearance systems for Minnesota DOT such as the PrePass® and NORPASS systems • Indicates many states are moving towards virtual weigh stations as they do not require transponders in trucks for pre-clearance
Hitchcock *et al.* 2012	• Tests a bridge WIM system (SiWIM) for enforcement application in Alabama • Finds that a maximum of two lanes on a bridge and steady

Key document	Contributions to current research effort
	travel velocity improves successful vehicle capture (rigid short span bridges are preferred)
Han *et al.* 2012	• Tests adaptive WIM threshold algorithms that dynamically alter the weight threshold of advanced WIM sorting systems for inspection stations as they near capacity • Finds that adaptive WIM threshold algorithms increase inspection station throughput without large capital investment, decrease the time inspection stations are closed, and remove a greater proportion of commercial vehicles with weight violations
Jones 2012	• Discusses the use of Truckscan in New South Wales, Australia, which pre-screens trucks using WIM and license plate readers to identify high risk trucks that should be stopped for inspection and low risk trucks that can by-pass an enforcement facility
McBride and Kirby 2012	• Identifies three high-level concepts of operation that utilize strategic electronic monitoring: (1) direct automated enforcement; (2) automated inspection with targeted intelligence driven enforcement; and (3)electronic screening with low-speed/static inspection
Lee and Chow 2011	• Develops a simulation model to reveal that e-screening improves overweight enforcement and that these improvements are enhanced as transponder adoption increases
NTC 2011	• Concludes that the use of on-board mass technology as a means of supporting truck weight enforcement in Australia should be "on a predominantly voluntary basis" by carriers as a means of meeting weight compliance regulations
OECD 2011	• Indicates that in Australia, recent findings show that the accuracy levels and tamper-resistant capabilities of on-board weighing technologies are now sufficient for regulatory enforcement applications • States that the Australian Intelligent Access Program uses satellite-based vehicle position and tracking technologies to ensure that trucks adhere to relevant highway network restrictions
Hanson *et al.* 2010	• Finds that after implementation of an advanced WIM sorting system the inspection station required 23 percent of commercial vehicles to stop versus the 60 to 70 percent that were required to stop previously
Kwon *et al.* 2010	• Tests a high-speed WIM system in Korea that includes a "wandering sensor" to detect the relative position of the driving vehicle in the lane and to increase the accuracy of

Key document	Contributions to current research effort
	vehicle classification for lift axle configurations • Finds the HS-WIM system to have a European COST323 accuracy of class B+(7) due to the error range of the axle group performance which is not suitable for direct enforcement
Cambridge Systematics 2009a	• Identifies Washington State's Commercial-vehicle Roadside Information Sorting System (CRISS) as an example of how high-speed WIMs are utilized for fixed weigh station operations • Discusses the use of WIM systems for mobile screening as a form of pre-selection for enforcement • Discusses how WIM sites can be upgraded to virtual weigh stations by the addition of a digital imaging system to identify potential violators (Indiana estimates the retrofit cost to be approximately $30,000)
Cambridge Systematics 2009b	• Describes the following standard applications of roadside technologies: traffic monitoring WIM systems, mobile screening at WIM sites, virtual weigh stations, fixed site-based mainline weight screening, and ramp sorting • Reveals that despite deployment of technology for pre-selection, enforcement activities are still limited to the number of enforcement personnel on duty at any given time in a region because citations can only be issued once a human weighs a truck • Indicates that motor carriers express concerns about data generated from roadside enforcement activities; the concerns include data retention time, usage beyond tangible goals in the public's interest, and data being leaked to their competitors
Cambridge Systematics 2009c	• Lists the benefits of license plate readers and other automatic vehicle identification technologies • Indicates that on-board scales help expedite the inspection process at weigh scales thereby reducing enforcement costs
Hahn and Dansare 2009	• Concludes that a VWS improves the effectiveness of vehicle selection methods • Finds no relationship between weight and safety violations
Jacob and van Loo 2008	• Concludes that the two technologies which are able to fulfill the requirements for enforcement (defined as class A(5) of the COST323 Specification) in the traffic flow are the multi-sensor (MS-) WIM and the bridge (B-) WIM
Jones 2008	• Investigates the effectiveness of combining high-speed WIM sensors with overhead mounted automatic number plate recognition cameras

Key document	Contributions to current research effort
Marchadour and Jacob 2008	• Finds that low-speed WIMs (4.5 km/h max speed) installed on a concrete slab could be used for direct enforcement • Conclude that high-speed WIMs are inadequate for direct enforcement
Stanczyk *et al.* 2008	• Finds that a virtual weigh station has a B(10) accuracy according to European COST323 specifications which is acceptable for pre-screening
Honefanger *et al.* 2007	• Evaluates technologies used for commercial vehicle size and weight enforcement in six European countries • Identifies four enforcement technology-related implementation opportunities from European countries that would have the greatest potential benefit for commercial motor vehicle enforcement in the U.S.: (1) bridge WIM; (2) heavy goods vehicle control facility (equipped with weight and dimensions measurement technologies); (3) pre-screening for mobile enforcement; and (4) WIM for direct enforcement
Cambridge Systematics 2006	• States that virtual weigh stations are "cost-effective" for size and weight enforcement and are "particularly effective" in urban areas where fixed weigh scales are uncommon
Rooke *et al.* 2006	• Describes six Use Cases to define the behavior of a system used for enforcement: (1) human selection; (2) statistics and planning; (3) pre-selection; (4) problem solving; (5) direct enforcement; and (6) intelligence

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding application and performance of enforcement technologies:

- Intelligent Imaging Systems, Inc. (2013, p. VII-1) supplemented their Smart Roadside electronic screening software "network" platform in New York State to include a trailer/rear automated license plate recognition (ALPR) device, a vehicle over-height detection system (OHD), and a hazardous material placard reader (AUR/HAZMAT). Based on 240 vehicles, the combined day and night read rate performance of the rear ALPR and AUR/HAZMAT devices was 43.75 percent and 70.71 percent, respectively.

- CDM Smith (2012, p. 4) reviews multi-state weigh station pre-clearance systems for Minnesota DOT. Trucks that are part of pre-clearance programs are fitted with transponders that communicate their size, weight, and identification to roadside readers. Additionally, their unique identification is matched against a database that contains information on the recent safety and credentials of the carrier and truck. If the data indicates compliance then the truck is given authority to by-pass the scale. The authors identify two multi-state pre-clearance systems available to state DOTs and note that two states have developed their own systems. However, many states are moving towards virtual weigh stations as they do not require transponders in trucks for pre-clearance. The two multi-state pre-clearance systems are described briefly below:

- PrePass® has adopted the Inspection Selection System (ISS) developed by the Federal Motor Carrier Safety Administration (FMCSA) as its primary criteria for safety clearance. Many PrePass® systems do not include mainline WIM sensors. PrePass® operates in 31 States with over 305 sites.
- NORPASS operates in eight states but was giving consideration to migrate their system to PrePass®.

- Hitchcock *et al.* (2012, p. 59) test the SiWIM system, a bridge WIM system developed by CESTEL, for enforcement application in Alabama. They find that: (1) SiWIM systems can be installed in one day and calibrated in an additional day after completing ten acceptable calibration runs in each lane; and (2) a maximum of two lanes on a bridge and steady travel velocity improves successful vehicle capture (rigid short span bridges are preferred).
- Han *et al.* (2012, p. 268) test adaptive WIM threshold algorithms that dynamically alter the weight threshold of advanced WIM sorting systems for inspection stations as they near capacity. The results show that fewer commercial vehicles enter the inspection station as it fills up and those that do are selected by a heavier weight threshold. Adaptive WIM threshold algorithms increase inspection station throughput without large capital investment, decrease the time inspection stations are closed, and remove a greater proportion of commercial vehicles with weight violations.
- Jones (2012, pp. 4-6) describes a technology used in New South Wales in Australia called Truckscan. This technology pre-screens trucks using WIM and license plate readers to identify high risk trucks that should be stopped for inspection and low risk trucks that can by-pass an enforcement facility. Technologies such as WIM and others are used to determine the vehicle's weight (axle and gross), height, length, classification, and speed. A video camera captures a vehicle's license plate which is used to determine the vehicle's status in a national database, its registration number, and historical information (*e.g.,* citations). Truckscan considers 36 criteria in establishing the risk of a truck and uses an algorithm to compute a risk score. The time to compute the risk is about six seconds.
- McBride and Kirby (2012, p. 8) indicate that transport operators who elect to voluntarily share their electronic vehicle data may be held to alternative enforcement intervention. This may include authorization to by-pass active weigh sites with a view to increasing productivity and encourage compliance. Electronic vehicle data could include position, road user charges, engine management, and driver identification data.

  The authors also identify (2012, p. 39) three high-level concepts of operation that utilize strategic electronic monitoring (SEM): (1) direct automated enforcement, (2) automated inspection with targeted intelligence driven enforcement, and (3) electronic screening with low-speed/static inspection. They indicate direct automated enforcement as the most direct and productive high-level concept that utilizes SEM. Direct automated enforcement relies on road side technology to detect vehicles operating outside a specified range and automatically notifies the operator/driver/owner with an infringement notice requiring no police enforcement resources. The implementation of such a concept requires significant political will as it will most likely occur simultaneously with changes to current governing laws for heavy commercial vehicles.

The authors recommend (2012, p. 57) SEM that consists of these primary high-speed technologies:

- An evidential grade high-speed WIM system that meets the updated international WIM Specification standard OIMLR134.
- 3D cameras equipped with infra-red and color capture that utilize image processing software to accurately calculate vehicle characteristics including speed, following distance, vehicle classification (height, width, length), among others.
- 2D cameras for side views to confirm axle groups. When coupled with automated number plate recognition systems, these systems can identify vehicles that avoid inspection stations.

- Lee and Chow (2011, pp. 92, 99, 102) develop a simulation model to estimate the effectiveness of e-screening (*i.e.,* screening trucks upstream of an inspection station using WIM) and the effect of transponder adoption in the effectiveness. The researchers apply the model to a small weigh scale station in Canada (Port Mann, British Columbia) with a short queuing area and high truck volumes. Transponders are used to automatically send the credentials of the truck and driver to the weigh station as the truck approaches the weigh scale. This information helps the enforcement officers determine if the truck should be inspected for purposes other than weight (p. 92). The authors find that e-screening improves overweight enforcement and that these improvements are enhanced as transponder adoption increases. The model shows an enforcement rate of 99.0 percent when 75 percent of the trucks have transponders and 49.9 percent when none of the trucks have transponders (p. 99). Overall the study finds that at least 20 percent of the trucks passing the station must have transponders to show any type of enforcement benefit (p. 102).
- Australia's National Transport Commission (2011a, p. vi) investigates the deployment of on-board mass technology as a means of supporting truck weight enforcement in Australia. The Commission evaluates three options, including "business as usual," mandatory installation, and voluntary installation. They conclude that the use of on-board mass systems should be "on a predominantly voluntary basis" by carriers as a means of meeting weight compliance regulations. Mandating the use of a specific technology restricts carriers in how they may develop cost effective weight compliance management systems. However, it is understood that repeat violators may need more prescriptive measures.
- OECD (2011, p. 290) indicates that the WIM technology for direct truck weight enforcement remains an emerging practice in most countries today. That is, an overweight measurement recorded dynamically at high-speed by a WIM device is not normally used as the sole evidence of an overweight violation. Nevertheless, WIM applications for enforcement include:

- the use of WIM as a pre-screening tool to identify and direct vehicles likely to be overweight to a traditional static weigh scale site for weight validation;
- WIM monitoring to identify times and places in which overloading may be more problematic, so that enforcement activities can be better targeted; and
- WIM monitoring of bypass routes to support other enforcement activity.

The report also comments on several other truck weight enforcement technologies:

- On-board weighing systems have been used by carriers for certain industry sectors as a tool to help avoid inadvertent overloading. In Australia, recent findings indicate that the accuracy levels and tamper-resistant capabilities of these technologies are now sufficient for regulatory enforcement applications (p. 290).
- The Australian Intelligent Access Program uses satellite-based vehicle position and tracking technologies to ensure that trucks adhere to relevant highway network restrictions (which are defined based on truck size and weight limits) (p. 292).
- Data capture, storage, analysis and reporting technologies will enable "more effective compliance and enforcement" through better targeting of high-risk drivers and operators and automated enforcement of violations without human intervention (p. 292).

- Hanson *et al.* (2010, p. 8) evaluated the percent of commercial vehicles being required to report to an inspection station in Nova Scotia, Canada before and after the installation of an advanced WIM sorting system was implemented in 2007. They found that after implementation the inspection station required 23 percent of commercial vehicles to stop versus the 60 to 70 percent that were required to stop previously. There was also a 27 percent decline in citations from 2005 to 2007 after implementation.

  The authors also document (p. 10) the use of a VWS in Newfoundland and Labrador, Canada for follow-up enforcement of commercial vehicle violations. The VWS system includes a quartz WIM sensor and multiple cameras that are triggered by inductive loops. The cameras are configured to only collect images of the violating commercial vehicles that are identified in real-time by the WIM device. The data are filtered and used to notify carriers with "non-compliance tendencies" that they may be subject to further enforcement.

- Kwon *et al.* (2010, p. 6) test a high-speed WIM (HS-WIM) system in Korea that includes a "wandering sensor" to detect the relative position of the driving vehicle in the lane and to increase the accuracy of vehicle classification for lift axle configurations. This system is found to be effective at detecting five-axle trucks with a lift-up axle. The HS-WIM sensor accuracy is tested following European COST323 WIM specification test conditions. The accuracy of the system is within 5 percent for gross weight error but receives a COST323 accuracy of class B+(7) due to the error range of the axle group performance.

- In their 2009 state of the practice report for the FHWA, Cambridge Systematics (2009a, p. 2-6) states that the use of WIM technology for direct enforcement activities is "not a target of the FHWA or state Departments of Transportation (DOTs) or law enforcement agencies." Rather WIM technology is commonly used for the pre-selection of vehicles that have a higher risk of being non-compliant, and effectively reduces the amount of compliant trucks that are inspected. Further, they have been developed to virtually screen vehicles in real-time at inspection stations that are unstaffed.

The report (p. 3-3) discusses the recent increase in WIM use on inspection station approach ramps in the U.S. This configuration takes advantage of a commercial vehicle's reduced speed to obtain more accurate axle weights. Inspection officers set the weight thresholds and vehicles that exceed that threshold must stop for further inspection. Four of the nine states that participated in the study have five or more of these weigh stations.

In particular, the report identifies Washington State's Commercial-vehicle Roadside Information Sorting System (CRISS) as an example of how high-speed WIMs (HS-WIM) are utilized for fixed weigh station operations. Washington State has installed WIM sensors coupled with cameras at 14 of its weigh stations that provide coverage for over 80 percent of the commercial vehicle fleet. The CRISS software provides inspection officers with an image of each commercial vehicle along with its weight information and an algorithm determines if there are potential axle weight violations.

Finally, the report (p. 4-3) discusses the use of WIM systems for mobile screening as a form of pre-selection for enforcement. Inspection officers at the roadside receive real-time vehicle weight information wirelessly from a WIM system located upstream and use it to intercept potentially overweight trucks for further inspection. This type of enforcement pre-selection can be achieved at a relatively low cost as any WIM system can be upgraded to have wireless connectivity. Mobile screening sites require WIM sensors, a roadside processor, wireless connectivity, a data receiver in the patrol car, and a laptop with the appropriate software. The inspection officer must be near enough to the WIM site to be able to visually identify vehicles as they pass over the sensors. The authors find that states consider mobile screening to be "well worth the costs" particularly when existing WIM systems are upgraded.

Similar to mobile screening, virtual weigh stations rely on WIM systems to provide weight information of vehicles but they are enhanced by a digital imaging system to identify potential violators. This reduces the need for permanent on-site staff as potential violators can be identified by officers remotely from multiple images of the vehicle. Indiana estimates the cost to retrofit existing WIM sites to virtual weigh stations to be approximately $30,000 USD. The digital imaging system can be further enhanced with optical character recognition (OCR) software to relieve the need for manual vehicle identification by providing a license plate number. This is particularly important in areas with high truck traffic volume.

- Cambridge Systematics (2009b, p. 2-1) interviews nine States that are at the forefront of the deployment of roadside technologies. They found the following standard applications of roadside technologies:
  - *Traffic monitoring WIM systems* are primarily used for planning activities but can help target enforcement resources.

- *Mobile screening at WIM sites* require that the WIM system has wireless connectivity so that an enforcement officer can physically monitor the real-time WIM data on a laptop from the roadside. The officer must be close enough to the WIM site to visually match the commercial motor vehicle (CMV) with its WIM data. Potential violators are intercepted for further inspection at a stationary weigh station or a mobile weigh station.
- *Virtual weigh stations* consist of a mainline WIM system, high-speed communication, and a camera system that eliminates the need for an officer to be on site to match the CMV with its WIM data. Virtual weigh stations (VWS) can be enhanced with optical technologies that have automatic vehicle identification (AVI) capabilities that may be integrated with additional information from safety and vehicle databases.
- *Fixed site-based mainline weight screening* relies on a mainline WIM system to screen CMVs traveling at highway speeds for weight compliance as they approach a weigh station. Potential violators are signaled to pull-in to the station for further inspection. When coupled with an electronic screening or bypass system, CMVs may be verified for bypass eligibility based on their weight, safety, and credential information.
- *Ramp sorting* utilizes a WIM system on weigh station ramps to screen CMVs by weight as they approach weigh stations travelling at low speeds. Once CMVs are weighed they are signaled to either proceed to the static weigh scale or to return to the highway via a bypass lane. WIM sensor accuracy is higher for ramp sorting applications than mainline WIMs due to lower travel speeds.

The report provides the following findings concerning WIM systems:

- Data from traffic monitoring WIM systems can be used for the informed placement of future WIM systems to aid in enforcement activities and to identify the most productive locations, days, and times for enforcement activities. This can be accomplished by quantifying factors temporally such as truck traffic volume and the frequency of overweight trucks (p. 2-2).
- Despite deployment of technology for pre-selection, enforcement activities are still limited to the number of enforcement personnel on duty at any given time in a region because citations can only be issued once a human weighs a truck (p. 2-10).
- The costs of WIM systems (per lane) based on actual implementation experience in the U.S. is as follows: piezoelectric—$16,000; quartz piezoelectric—$29,000; bending plate—$40,000; and single load cell—$87,500. The more expensive systems are found to be more intrusive to the pavement structure but have an increased service life. The accuracy of the piezoelectric WIM is less than the other technology devices at 85 percent compared to 95 percent (p. 2-8).
- A typical weigh station can cost anywhere from $12 million to $300 million depending on the land purchase requirement. Alternatively, based on fund requests from the Federal Motor Carrier Safety Administration (FMCSA) from 2006 to 2008, VWSs cost from $300,000 to $1,400,000 depending on additional enhancements like AVI technologies. One State indicated that the cost to upgrade an existing WIM site with mobile screening capabilities was marginal. Many States are choosing to deploy

VWS and mobile screening due to the "increased scope of enforcement activities at less cost and staff than are required by weigh stations operations" (p. 2-8).

- Motor carriers express concerns about data generated from roadside enforcement activities. The concerns include data retention time, usage beyond tangible goals in the public's interest, and data being leaked to their competitors (p. 2-11).

- Cambridge Systematics (2009c, p. ES-19) lists the following benefits of license plate readers and other AVI technologies: (1) enable officers to target likely offenders; (2) improve data collection; and (3) enable timely access to safety, credentials, and criminal records.

  The report also indicates (p. 3-7) that on-board scales can be used to monitor truck weight. Information can be extracted from the devices for enforcement purposes by directly plugging into the device or via a wireless connection. The devices help expedite the inspection process at weigh scales thereby reducing enforcement costs. The accuracy of these devices is "still questionable." In addition to weight, on-board equipment can also be used to monitor brake and tire conditions, lighting, steering, suspension, exhaust, and horn operation.

- Hahn and Pansare (2009, pp. xiv-xvii) provide detail on Maryland's implementation of Virtual Weight Stations which are intended to augment current enforcement activities at fixed facilities and mobile patrols.

  In Maryland, the goals of the VWS pilot project are: (1) to provide a platform for helping law enforcement personnel target enforcement activities; (2) to develop a "stable, accurate, and standard platform for rapid deployment at other statewide locations"; (3) to determine, from a research perspective, whether a relationship between weight and safety exists; and (4) to provide recommendations and guidelines in expanded deployment of the VWS concept.

  The pilot project deployment involved two phases of tests. The first phase involved a predefined set of vehicles and confirmed that the VWS met relevant technical requirements. The second phase involved a set of on-road vehicles and also confirmed that the VWS met technical requirements (except for the gross weight requirement which was "not met completely").

  Data collected by the VWS provide "valuable clues to focus their inspection efforts during time periods that suggest more over weight and/or over height violations." No relationship between weight and safety violations was observed. The study concluded that the VWS "improved the effectiveness of CMV selection methods significantly over a traditional method relying on random selection."

  [A follow up discussion with Maryland State Police and Maryland State Highway Administration in August 2013 revealed that current VWS and future VWS (22 total VWS stations by 2017) will incorporate Drivewyze Inc.'s PreClear service. Drivewyze is an "inspection site bypass system which adds transponder-like functionality to tablet computers and smart phones, and enables enforcement officers to electronically pre-screen trucks travelling at highway speeds (Transport Topics 2013, p. 15)."]

- Jacob and van Loo (2008, p. 33) conclude that the two technologies which are able to fulfill the requirements for enforcement in the traffic flow are the multi-sensor (MS-) WIM and the bridge (B-) WIM. The requirements for WIM accuracy, defined as class A(5) of the COST323 Specification, are ± 5 percent for gross weights, ± 8 percent for axle group loads, and ± 10 percent for single axle loads with a confidence level greater than 96 percent. The use of these technologies for vehicle weight enforcement depends on the legal certification of high speed (HS-) WIM systems.
  - MS-WIM systems can only achieve class A(5) tolerances if they are set up in arrays of eight to 16 sensors. This requires highly efficient algorithms, accurate and reliable strip sensors, powerful calibration procedures, and detailed quality assurance.
  - B-WIM systems have been shown to achieve class A(5) tolerances on some types of bridges for gross vehicle weight and axle group loads. The benefits of B-WIMs are that they are almost undetectable by drivers and do not require lane closures for installation and maintenance.
- Jones (2008, p. 265) investigates the effectiveness of combining high-speed WIM sensors with overhead mounted automatic number plate recognition (ANPR) cameras to better identify vehicles in violation of truck size and weight regulations in the United Kingdom. This system is connected to an ANPR database containing individual permitted maximum axle and gross weight limits for all U.K. registered trucks, buses, and coaches. This connection enables the system to classify vehicle configurations that are difficult for WIM sensors to classify and has had an “enormous benefit.” The weight threshold for potential violators was set at eight percent overweight by axle or gross vehicle weight. This results in an average of 240 overweight alerts per day of which six percent are inspected due to staffing limitations. The research finds a 90 percent overload prohibition issue rate to number of vehicles identified.
- Marchadour and Jacob (2008) describe the development and implementation of a WIM network for enforcement in France. They tested low-speed WIMs (maximum vehicle speed of 4.5 km/h) installed on a concrete slab (36 m by 4.5 m) and found that they could be used for direct enforcement and could be installed and removed to different sites (p. 268). They also tested high-speed WIMs (maximum speed not specified) and found that they were inadequate for direct enforcement but useful for screening potentially overweight trucks (p. 269).

  The authors develop a national WIM network with three objectives (p. 269):
  - Pre-select and identify overloaded or speeding trucks prior to a weigh scale station
  - Identify frequently overloaded carriers
  - Gather statistical traffic data to determine the most overloaded road sections and time periods

  To achieve these objectives, the researchers installed video-WIMs at selected sites upstream of a weigh scale which collected the following information (p. 271):
  - Vehicle classification (22 categories)
  - Axle loads and GVW
  - Speed and length
  - License plate information

These systems identify trucks that are potentially overloaded or speeding and send the data to a central server and to officers at the downstream weigh station. If officers are on duty, they use the data to select vehicles to inspect. These data are centrally stored and analyzed to identify frequently speeding or overloaded carriers (p. 271).

- Stanczyk *et al.* (2008, p. 290) test a virtual weigh station in France for accuracy. The authors recorded an accuracy of B(10) according to COST323 specification which is acceptable for pre-screening. They report that 96 percent of pre-selected vehicles were overloaded.
- Honefanger *et al.* (2007, p. 2) evaluate technologies used for commercial vehicle size and weight enforcement in six European countries as part of the FHWA-PL-07-002 report. They find the following:
  - Two of the six countries use technology for vehicle size enforcement that includes an automated profile measuring device and a gantry laser scanner. For speeds less than 10 km/h these systems provide an accurate dimensional picture suitable for legal enforcement. In high-speed applications they can be used for pre-selection.
  - Bridge WIM systems have been successfully implemented in Slovenia, are undergoing tests in France, and have sparked interest in other EU countries. Slovenia has found most success with WIM systems on short, stiff bridge structures.
  - Piezoquartz or piezoceramic WIM sensors have been consistently used for roadway applications in the European countries who took part in the scan.
  - The accuracy of WIM systems is sufficient for pre-selection but not for direct automated enforcement. France and the Netherlands are researching the accuracy of multiple-sensor WIM systems for direct enforcement. While it was not observed as part of the study, the United Kingdom, Belgium, and Germany are reportedly already using low-speed WIM systems for direct enforcement.

Honefanger *et al.* (p. 5) also identify seven specific implementation opportunities from European countries that would have the greatest potential benefit for commercial motor vehicle (CMV) enforcement in the U.S. Four of these implementation opportunities involve enforcement technologies.

- *Slovenia bridge weigh-in-motion*: This involves weight-detection instrumentation installed under the bridge deck without disrupting traffic flow on the bridge. Once bridge deck substructures have been instrumented they can be easily removed and installed elsewhere on a rotational basis. The selection of a suitable bridge and the calibration of the B-WIM sensors may involve a high level of expertise.
- *Swiss heavy goods vehicle control facility*: This facility pre-selects CMVs using a HS-WIM combined with video technology. Potential violators are intercepted for static weighing while an overhead gantry fitted with laser scanners measures CMV width and height simultaneously.
- *Prescreening for mobile enforcement*: While the U.S. uses this approach to varying degrees there is a need for a comparative analysis with European state of practice.
- *Applying WIM for direct enforcement*: French officials are leading the way to overcome the institutional barriers that prohibit the use of low-speed WIM

technology for direct enforcement while the Dutch are focused on acceptance of high-speed WIM technology.

- Cambridge Systematics (2006, p. D-11) outlines two specific benefits of virtual weigh stations. First, these stations enable officers to target enforcement efforts on overweight vehicles, which reduces the amount of time used for weight enforcement at fixed weigh scales. Second, these stations are suitable for monitoring routes used by operators to by-pass fixed weigh scales, thereby targeting enforcement efforts and improving compliance. The report states that virtual weigh stations are "cost-effective" for size and weight enforcement and are "particularly effective" in urban areas where fixed weigh scales are uncommon.
- Clough Harbour & Associates LLP (2006, p. 19) perform a review of license plate recognition (LPR) technologies for the New York State Department of Transportation. They conclude that LPR "is not ready for, and in fact may never be best suited for mainline screening." The authors recommend that LPRs be installed as part of virtual WIM sites but used primarily as a data collection device. They also indicate that funds set aside for LPR screening would be better spent on regional transponder enrollment efforts as they "will always offer a safer more accurate method of commercial vehicle screening."
- Rooke *et al.* (2006, p. 38) identify six Use Cases for the EU's project REMOVE which seeks to provide a framework for WIM systems to reduce danger and damage caused by overweight vehicles. Use Cases are used to define the behavior of a system used for enforcement. They are listed below by level of technical difficulty or technical integration (beginning with the least difficult):
  - *Human selection* is the traditional way of enforcement where officers use their experience to select potentially overloaded vehicles. No WIM devices are used in this application.
  - *Statistics and planning* uses data collected from WIM systems to target enforcement activities temporally and increase the efficiency of enforcement resources. This also includes the measurement of damage to the infrastructure.
  - *Pre-selection* relies on WIM systems to select potential offenders for further inspection by static scales. Pre-selection optimizes the ratio of citations given by number of vehicles inspected. This application includes mobile screening and virtual weigh station technologies.
  - *Problem solving* attempts to achieve compliance by solving the problems that underlie offenses. Problem solving can be applied two ways:
    - *Direct feedback* – a WIM system is used to warn passing vehicles if they are potentially overweight and directs them to off load locations.
    - *Company profiling* – involves collecting data and images from WIM systems of violators, using license plate numbers to identify the responsible company, and creating company profiles of their level of compliance. Based on their compliance level companies may be issued a warning letter or subjected to a company visit.

- *Direct enforcement* uses the weight measurements from WIM systems for the direct weight enforcement of trucks similar to that of automatic speed enforcement. The threshold at which vehicles are found in violation is dependent on the accuracy of the WIM sensor and in this way "enforcement focuses on the more severe cases of overloading."
- *Intelligence* involves a collection of applications and the aggregation of data collected from each of them into intelligence for policing or enforcement application.

- Gu *et al.* (2004, p. 7) evaluate the use of WIM technology to reduce delay and improve enforcement at weigh scales through the use of micro-simulation software. The report evaluates weigh station design and operation by simulating different design strategies (one static scale, two static scales, ramp WIM scale, and mainline WIM scale), the impact of weight threshold used, WIM accuracy, and the percentage of trucks in the traffic stream equipped with transponders. The following conclusions are made: (1) the use of WIM technology improves the efficiency of weigh scale operation; (2) at least 30 percent of trucks should be equipped with a transponder (used to inform drivers if they need to enter the weigh scale) for mainline WIM operation to be effective; (3) due to the current level of transponder usage in the fleet (less than 30 percent), WIM scales are more effective on weigh scale ramps than on mainlines; (4) accuracy of WIM scales is "an important issue;" and (5) threshold levels are important to achieve a balance between weigh scale efficiency and effective enforcement.
- TRB (2002, pp. 179-182) describes the use of automatic clearance systems (such as PrePass), which screen trucks on the road and allow non-violators to by-pass enforcement stops. These systems improve enforcement efficiency by enabling officers to target trucks more likely to be in violation, thereby reducing the cost of enforcement for the public sector and the enforcement-related costs incurred by carriers. The study discusses extended applications of AVI technology, specifically in terms of permit enforcement, identification of repeat offenders, and automated on-board enforcement techniques. The study also identifies the need for databases and information systems to improve enforcement efficiency. Data needs include inspection histories and violations of size and weight, safety, and other truck regulations. "Data must be accessible in the field, comprehensive, and current."
- Berthelot *et al.* (2001, p. 203) discuss an automated vehicle monitoring and compliance audit system that facilitates the Saskatchewan Partnership Haul Program. "The automated vehicle monitoring system has the ability to continuously monitor and sample data from a wide variety of onboard vehicle sensors" (for example, data from onboard global positioning systems (GPS), central tire inflation (CTI), and air-spring suspension weight sensors). The vehicle weight can be determined by the pressure in the air-spring suspension system to an accuracy of ± 5 percent. This information is transferred to the central administration system, where it can be queried at any time by officials involved in the program. Vehicle routing, non-compliance, and audit reports are generated by the central administration system.

- USDOT (2000, pp. VII-13 and VII-14) suggests that the use of WIM as a pre-screening device at fixed weigh scales "improve[s] the efficiency and effectiveness of operations." The report also indicates that WIM devices require frequent maintenance and may not provide continuous operation. The report identifies the integrated use of WIM and photo imaging as a plausible option for issuing weight citations.
- USDOT (2000, p. VII-14) identifies AVI systems, AVC systems, and bar codes and readers as prospective vehicle identification technologies that could be used to support truck size and weight enforcement, provided that the supportive information systems could be developed.

CHAPTER 7 - ALTERNATIVE APPROACHES FOR ACHIEVING COMPLIANCE

Table 9 summarizes the findings from Chapter 7 that are most relevant to the current research effort.

Table 9. Key Documents Summary for Chapter 7

Key document	Contributions to current research effort
Jones 2012	• Identifies the need for regulators (in Australia) to provide advice to shippers about how to manage their chain of responsibility obligations when trucks are overloaded • Finds that high-quality and timely data are necessary to differentiate between low and high risk operators • Reports interest (in Australia) in providing incentives to achieve compliance
NTC 2011b	• Concludes, based on an international scan of best practices, that the dualistic compliance versus enforcement (deterrence) thinking has evolved into a wider range of options, with no internationally-accepted best practice • Identifies an emerging approach known as informational regulation, which provides information on the operations of regulated entities to affected stakeholders, who then exert pressure on the regulated entity to improve compliance • Emphasizes the need for rewards-based compliance tools
OECD 2011	• Lists several issues with traditional truck weight enforcement approaches which inhibit enforcement effectiveness • Identifies consistent, targeted enforcement as one of a set of compliance-enhancing tools, which also includes incentives-based strategies, training/education initiatives, monitoring compliance levels and effectiveness, and ongoing research • Identifies accreditation as one alternative compliance strategy • Describes the chain of responsibility principle, which extends responsibility to ensure weight compliance to all who have direct or indirect control over a transport operation • Emphasizes the adoption of technologies and legislation reform as necessary enablers of the chain of responsibility principle
Walker 2010	• Suggests the need for a two-track regulatory structure, where certain operators demonstrate compliance through an accreditation scheme, while others remain subject to more traditional enforcement
Cambridge Systematics 2009a	• Identifies Minnesota's relevant evidence weight enforcement program • Emphasizes the need for cooperative relationships with trucking associations and carriers to successfully deploy roadside enforcement technologies

Key document	Contributions to current research effort
Cambridge Systematics 2009b	• Recommends expanded educational initiatives to promote voluntary compliance within future enforcement programs in Wisconsin
Honefanger *et al.* 2007	• Finds that, in Europe, there is greater use of mobile enforcement activity than fixed enforcement activity • Identifies high levels of multidisciplinary collaboration • Identifies an emphasis on the application of WIM technologies for pre-selection in Europe • Contends that direct enforcement by high-speed WIM systems are five to 20 years in the future
Fekpe *et al.* 2006	• Proposes a performance-based compliance program and measures to evaluate performance that differentiate trucks by configuration, commodity, and highway type • Suggests structuring permit fees based on axle loads • Identifies the need for information technologies to administer performance-based permit programs
Rodier *et al.* 2006	• Identifies two implementation barriers of virtual compliance stations: (1) hesitance from carriers concerning confidentiality and operating costs; and (2) public agency concern about high implementation costs, lack of expertise to operate them, and skepticism about their accuracy • Identifies potential legal constraints relevant to implementation of virtual compliance stations
URS 2005	• Recommends establishing a network of virtual WIM stations to measure compliance • Provides considerations for implementing virtual WIM stations • Identifies input, output, and outcome measures within a performance-based compliance program
Leyden *et al.* 2004	• Indicates that adopting accreditation systems and providing various benefits to accredited operators can serve as a powerful mechanism for compliance but also increase the efforts of regulators • Describes the chain of responsibility principle as applying to consigning, loading, carrying, driving, and receiving • Identifies three categories for weight violation severity (minor, substantial, severe) • Discusses a hierarchy of sanctions (sometimes referred to as the “enforcement pyramid”), ranging from improvement notices to prohibition orders
Johnstone 2002	• Notes that criticism of traditional enforcement approaches led Australia to develop the chain of responsibility principle

Key document	Contributions to current research effort
McIntyre 2002	• Outlines the National Transport Commission's (Australia) strategy for enhancing a compliance culture (this document was foundational for Australia's truck weight enforcement/compliance reforms as described above)
USDOT 2000	• Identifies the use of relevant evidence laws as one option to improve the effectiveness of size and weight enforcement programs • Indicates that the success of this approach in Minnesota had not been replicated in other states

Notes: Key documents are listed in the column on the left, with the corresponding contributions provided on the right. Only documents considered most relevant are included in this table.

Literature review and summary regarding alternative approaches for achieving compliance:

- Jones (2012) describes aspects of Australia's new enforcement program which includes concepts such as the chain of responsibility and using technology and data to improve enforcement and compliance. To create a culture where truck size and weight laws are nearly self-regulating, Australia is implementing the chain of responsibility concept and trying to achieve voluntary compliance. They are also introducing responsive regulation in legislation that provides regulators with a range of penalties that account for individual company risk and past performance. The lowest penalties require carriers to attend educational sessions which carry no financial impact or issue fines that are a fraction of what would normally be issued. The highest penalties can triple the fine or revoke vehicle or drivers licenses (pp. 9-10). The chain of responsibility concept has potential to be effective but the author finds that shippers were frustrated with this approach because regulators were unable to provide advice to them about how to manage their obligations when trucks were overloaded. The author concludes that the lack of policy forethought and practical guidance can hinder well-meaning intentions of the industry (p. 8).

  The author also finds the following:
  - High-quality and timely data are necessary for regulators to differentiate between low and high risk operators and to provide incentives to compliant operators and target non-compliant operators. However, Australia does not have the system in place to do this at a national level (p. 10).
  - Australia is interested in providing a reward- and incentive-based system for operators to achieve compliance. Some ideas for incentives are to dedicate varying levels of the transportation spending budget to truck-related initiatives based on the level of industry compliance, reduced registration and licensing costs for compliant operators, and reduced insurance premiums (pp. 10-11).

- Australia's National Transport Commission (2011b, pp. iii-iv) synthesized international best practices on achieving regulatory compliance. The report is relevant to trucking regulations, though it borrows from compliance and regulatory practices in other fields. In summary, the dualistic compliance versus enforcement (deterrence) thinking has evolved into a wider range of options, with no internationally-accepted best practice. More specifically, the report identifies seven regulatory strategies, including:

- Rules and deterrence, which emphasizes an "adversarial style of enforcement" and penalties for rule-breakers;
- Advice and persuasion, which emphasizes cooperation rather than confrontation to prevent harm and avoid sanctioning;
- Responsive regulation, which features a combination of the foregoing two strategies;
- Smart regulation, which expands on responsive regulation by emphasizing the role of the market and society in acting as a regulator;
- Metaregulation, which requires regulated entities to submit compliance plans for approval, with the regulator acting as a risk manager;
- Risk-based regulation, which emphasizes the need to adjust the regulator's response to non-compliance based on the risk that the non-compliant event poses to the regulator's objectives; and
- Criteria-based strategy, which enables a wide range of compliance and enforcement responses, chosen based on consideration of pertinent criteria.

The report also identifies five compliance assurance tools, including:

- Tools used prior to a regulated activity (*e.g.*, licenses, permits);
- Tools designed to encourage or reward compliance (*e.g.*, education, advice);
- Tools that remind an entity of regulatory responsibility (*e.g.*, prohibition notices);
- Tools involving penalties or sanctions; and
- Tools that use rewards and positive motivation to affect behavioural change.

Finally, the report identifies an emerging approach known as informational regulation, which provides information on the operations of regulated entities to affected stakeholders, who then exert pressure on the regulated entity to improve compliance.

The report concludes that there is a need to improve the scope of tools used to achieve compliance, by drawing strategically from those at the bottom and top of the 'enforcement pyramid' (which emphasize compliance and deterrence, respectively). Specifically, the need for more reliance on rewards-based tools and informational regulation is identified. When selecting an appropriate mix of tools, however, regulators should be aware that some combinations of tools may be counter-productive.

- The OECD (2011, pp. 281-282) quotes an Australian report by McIntyre and Moore (2002, p. 1), which lists the following issues with the traditional truck weight enforcement approaches:
  - "Fines, no matter how high, will not have a sufficient deterrent effect when the chance of detection is slight and the potential profits from offending are high.
  - Targeting only the truck driver and operator has no deterrent impact on the many 'off-road' parties who have a significant influence on on-road compliance and leads to a perception amongst drivers and operators that they are being treated unfairly.
  - In an industry characterized by high levels of competition resulting from low barriers to entry and a large number of small operators, the survival of operators who attempt to achieve levels of compliance higher than industry standards will be threatened.

- A culture founded on confrontation between the regulator and the regulated is not conducive to promoting voluntary compliance."

The report also suggests (p. 295) that the level of compliance achieved depends on:

- "The degree to which the target group knows of and comprehends the rules";
- "The degree to which the target group is willing to comply—either because of economic incentives, positive attitudes arising from a sense of good citizenship, acceptance of the policy goals, or pressure from enforcement activities"; and
- "The degree to which the target group is able to comply with the rule."

The report identifies consistent, targeted enforcement as one of a set of "compliance-enhancing tools," which includes incentives-based strategies, training of enforcement officers, industry education and communication, monitoring compliance levels and effectiveness, and conducting ongoing research.

The report identifies accreditation as one alternative compliance strategy (pp. 284-287). Accreditation is a voluntary or mandated arrangement in which an operator certifies compliance with specified regulatory requirements, and the regulator validates compliance through an auditing process. Accreditation schemes have been implemented for the purpose of ensuring compliance with truck size and weight limits, as well as other requirements such as route adherence, cargo handling, and safety. In some schemes, demonstrated compliance within an accreditation scheme enables carriers to operate beyond basic truck size and weight limits. In other words, productivity incentives are used as a means to achieve regulatory compliance for an accredited operator.

Illustrative descriptions of how accreditation schemes have been used within a truck size and weight enforcement program follow:

- Australia's National Heavy Vehicle Accreditation Scheme is a voluntary program that allows an accredited carrier to demonstrate compliance (via auditing) and thereby be subject to less frequent on-road enforcement activities. Operators may select to be accredited for maintenance management (which exempts qualified operators from annual inspections), weight management (which allows qualified operators to increase loads), or fatigue management (which provides qualified operators flexibility in hours of service restrictions).
- South Africa's Road Transport Management System is a voluntary accreditation scheme designed to improve compliance with weight and safety-related regulations by encouraging industries to take more responsibility for improving on-road safety and limiting infrastructure damage. The scheme is viewed as an instrument which can be used by various agents in the supply chain interested in improving corporate governance.

Another alternative strategy involves the use of the chain of responsibility principle, which is described as follows (p. 288):

"…all who have control, whether direct or indirect, over a transport operation bear responsibility for conduct which affects compliance and should be made accountable for failure to discharge that responsibility."

This principle can be applied to various aspects of on-road compliance. However, a pertinent example from a truck size and weight perspective is the penalization of a grain handling company which receives grain from overloaded trucks and rewards operators who do so.

Technological adoption and legislative reform are necessary enablers of the chain of responsibility principle. Technologies (*e.g.,* real-time tracking, electronic on-board recording devices) now enable many aspects of a freight transport task to be monitored remotely, thereby placing additional responsibility on the operator for assuring compliance. Legislative reform that requires all agents within a supply chain to ensure compliance or which reverse the onus of responsibility so that all parties are automatically deemed responsible for non-compliant behaviour support the chain of responsibility principle.

- Scott and Ferrara (2011, pp. 1, 7) develop a road vulnerability index (RVI) for North Carolina which is a weighted function of the relative truck exposure index (RTEI), pavement condition rating index (PCRI), and bridge severity index (BSI) on a road segment (p. 1). The RVI can be used to allocate enforcement resources to locations of highest vulnerability and help deploy roving enforcement efforts (p. 1). The RVI is still in the preliminary development and application stage. It is limited in its functionality since roads without truck data are removed (p. 7). The index helps enforcement personnel direct resources to preserve infrastructure based on roads with high truck volumes rather than increase compliance based on roads with high violations or low compliance.
- Walker (2010, pp. 17-18) discusses Australia’s evolving heavy vehicle regulatory approach, in particular recent implementation of the National Heavy Vehicle Accreditation Scheme (which provides concessions for accredited carriers) and the chain of responsibility principle (which places responsibility for non-compliance on all agents within the logistics supply chain). A series of stakeholder interviews reveals that the accreditation scheme has provided opportunity for better engagement between the regulator and the operators within an innovative and flexible regulatory structure. However, not all operators are interested in participating in such a scheme. Therefore, Walker suggests the need for a two-track regulatory structure, where certain operators demonstrate compliance through the accreditation scheme, while others remain subject to prescriptive regulations and more traditional enforcement. A two-track system has the potential to incentivize compliance and build on innovations already present within the accreditation scheme. However, risks of a two-track system include: unfair competition, complex enforcement, costly implementation, and potential abuse within the self-accreditation program.
- Cambridge Systematics (2009a, p. 4-6) discusses Minnesota’s relevant evidence weight enforcement program that allows state enforcement officials to examine weigh bills (relevant evidence) and issue civil penalties for overweight loads under statutory authority. The program is built around the law that all receiving sites in Minnesota must retain weight bills and allow access to enforcement officers within 14 days of when the shipment was received.

The report also emphasizes (p. 4-14) the need for a cooperative relationship to support the "successful deployment of roadside technologies." State trucking associations and carriers can be strong advocates for deploying enforcement technologies as they support leveling the playing field between compliant and non-compliant carriers.

- Cambridge Systematics (2009b, p. ES-19) recommends that future enforcement programs in Wisconsin should consider expanded use of educational initiatives which promote voluntary compliance with truck size and weight laws.
- Honefanger *et al.* (2007, p. 2) evaluate procedures used for commercial vehicle size and weight enforcement in six European countries as part of the FHWA-PL-07-002 report. They find the following:
  - There is a greater use of mobile enforcement activities than fixed roadside weigh scale facilities. The result is that fewer trucks are processed and inspection areas are physically constrained but there is more flexibility to respond to industry and more effective enforcement action.
  - There is a high level of multidisciplinary collaboration between different levels of government supplemented by input from the private sector.
  - WIM technology is applied to commercial vehicle enforcement through real-time pre-selection, optimizing enforcement activity scheduling, and targeting carriers with notices of non-compliance.
  - Many European enforcement agencies employ dedicated personnel for size and weight enforcement. Often these personnel are prohibited from performing duties beyond size and weight enforcement.
  - In 2007, France and the Netherlands indicated that direct enforcement by high-speed WIM systems are five to 20 years in the future.
- Australia's National Transport Commission (2007, pp. 1, 4) provides a report outlining the National Heavy Vehicle Enforcement Strategy, aimed at promoting consistent, effective and efficient enforcement in heavy vehicle transport law in Australia. The strategy follows the 2003 passage of a bill that, among other items, recognized the chain of responsibility principle within truck size and weight enforcement. As of 2007, however, not all Australian jurisdictions had adopted the bill's provisions; hence the development of the national strategy. The strategy identifies the following objectives to achieve the national compliance outcome:
  - Intelligence-driven enforcement requires information systems that help target enforcement activity and improve detection of violations.
  - Consistent, effective, and efficient enforcement practices emphasize cooperation between enforcement agencies and promote a more cohesive relationship between the industry and the regulator.
  - Cooperation and trust between industry and the regulator should be fostered to improve compliance.
  - Officer training designed to enable confident execution of enforcement tasks.
  - Improved communication between enforcement agencies provides an integrated means of recognizing and resolving issues.

- Fekpe *et al.* (2006) encourage the use of a performance-based compliance program and describe how this type of program may be designed and applied. The authors indicate that a performance-based program should be robust and simple to administer, implement and monitor, and should use performance measures (or surrogate measures) that are easy to obtain using simple and quick roadside tests (p. 4). They acknowledge that this may require an approach that differentiates trucks by configuration, commodity, and highway type in terms of enforcement and data collection (p. 4). They propose issuing oversize/overweight (OS/OW) permits that restrict vehicles to designated routes defined by road class and that have been shown to be capable of supporting OS/OW loads contained in a permit (p. 4). Permit fees should be related to infrastructure preservation but should be simple and practical to administer at a large national scale. The authors identify a permit fee option used in Saskatchewan that requires carriers to demonstrate the economic benefit of operating at higher weights and calculating their permit fee as 50 percent of the associated increased profit resulting from increased weight productivity. The authors recommend a simpler approach where fees are graduated based on axle loads (p. 5).

  The authors state that enforcement of performance-based programs requires the use of transponders and other electronic methods in addition to enforcement officers, regulations, special conditions, education and industry communication, fines and penalties, and adjudication (p. 8). They envision enforcement personnel collecting transponder data and transferring it to a central clearinghouse where reports could be produced to determine if the vehicle complied with the permit conditions (p. 9). Traditional enforcement programs which require drivers to possess a hard copy of the permit and present it to enforcement officers for inspection whereas performance-based systems would use intelligent transportation systems (ITS) to automatically determine the legality of a vehicle without requiring manual inspection of hard copy permits (p. 9). The authors suggest that violations should result in the permit being revoked and vehicle being suspended from operation (p. 8).

- Germanchev and Bruzsa (2006) describe a hybrid testing method to prove the compliance of heavy vehicles. Based on experience with Performance Based Standards in Australia, the authors find that the best method to assess the performance of trucks is a hybrid method consisting of simulation and field testing (p. 2). This approach inputs the specifications of truck configurations into a simulation model to predict how the vehicle will operate and behave under different conditions. The truck configuration is then tested in a private testing facility which replicates the driving conditions of the model. Field measurements are recorded and used to calibrate the model. Once calibrated, the model is used to determine the predicted performance of the truck configuration on different types of roadways in Australia to determine where this truck will be permitted to operate (p. 5). The authors find that the combination of simulation and field testing is a robust and accurate approach to predict the actual performance of a vehicle configuration under different conditions (p. 10).

- Rodier *et al.* (2006, pp. 127-132) find that virtual vehicle compliance stations (VCSs) can be located on potential weigh scale by-pass routes to effectively identify carriers that attempt to avoid weigh scales and to help enforcement officers target trucks with a higher probability of being overweight (p. 127). Their review looks at the institutional and legal barriers of installing virtual VCSs for pre-screening and enforcement.

The authors find the following regarding institutional barriers:

- Commercial vehicle (CV) operators are generally unsupportive of virtual VCSs due to confidentiality and operating cost concerns. CV operators feel like these technologies collect private information about their operations and that there is potential to use this technology to increase government regulations or impose a weight-distance tax. To help alleviate this barrier the authors recommend consulting with industry early in the process of establishing virtual VCSs to create awareness about the benefits of these systems (*e.g.,* time and fuel savings for compliant trucks being able to by-pass scales) (p. 128).
- Public agencies are concerned about virtual VCSs due to the potentially high cost to implement, the lack of technical expertise to operate them, and distrust by enforcement officers about their accuracy. There are also concerns that virtual VCSs could reduce felony arrests, create a negative image of officers as “sneaky,” deprive carriers of officer discretion, and face opposition by unions due to job security concerns. Some states or regions have existing pre-clearance programs and new virtual VCSs must interoperate with these programs. To overcome these barriers the authors recommend developing an incremental implementation strategy that begins with modest technologies, training programs, and staff requirements and ensuring proper communication and coordination between different government agencies and personnel (p. 129).

The authors find the following regarding legal constraints:

- There are concerns from CV operators that certain constitutional rights and protections may apply to automated enforcement programs; however, the authors find that virtual VCSs do not violate constitutional rights and freedoms.
- Amendment to state law is often required to use virtual VCSs for automated enforcement and may be required for non-voluntary pre-screening applications (*e.g.*, amendments that ensure business confidentiality). However, state laws may not require amendment for voluntary pre-screening applications (p. 130).

The research discusses program design elements to consider when implementing a virtual VCS as follows:

- *Vehicle owner versus driver citations*: If virtual VCSs are used for enforcement (as opposed to screening), issuing a citation to the registered vehicle owner based on the license plate (as opposed to issuing a citation to the driver) reduces the enforcement effort, limits the infraction to a civil penalty, and can be less effective in preventing future violations. If citations are issued to the driver (as opposed to the registered vehicle owner), the effort to match the identity of the driver to the photo taken at the virtual VCS becomes onerous and often inconclusive; however, the infraction can become a criminal offense which serves as a much stronger deterrent for future violations (p. 130).

- *Fixed versus mobile cameras*: Compared to mobile manned cameras, fixed unmanned camera locations are usually less costly to operate, can be operated 24 hours per day, and have a smaller footprint which may allow them to operate in more locations. However, mobile manned cameras provide better geographic coverage (p. 130).
- *Placement of virtual VCSs*: The authors recommend installing virtual VCSs only on routes with a significant violation problem or routes that could be used to by-pass a weigh station (p. 130).
- *Enforcement threshold*: If virtual VCSs are used for enforcement, states should set a threshold that is higher than the legal weight but below which they do not issue tickets to account for potential inaccuracies of weighing equipment.
- *Responsibility and authority for administering and operating virtual VCSs*: Legal challenges can arise if the state leases the video monitoring equipment and services necessary to operate the program from a vendor. Citations can be dismissed in court if the vendor is paid by the number of tickets issued, if vendors are allowed to select enforcement locations, or review tickets (p. 131).

The researchers suggest the following steps to address stakeholder barriers to implementation for using virtual VCS for screening and enforcement (pp. 131-132):
- "Start with smaller, less costly, and less controversial programs.
- Establish multiagency working groups early in the process.
- Include the judiciary in working groups if automated enforcement is being considered.
- Involve the Commercial Vehicle Operations (CVO) industry early in the planning and implementation process through advisory groups.
- Conduct targeted educational outreach efforts for agencies and the CVO industry.
- Document and communicate the costs and benefits of the program."

- Rooke *et al.* (2006, p. 51) consider liability of vehicle weight regulation violators for the EU's project REMOVE, which seeks to provide a framework for WIM systems to reduce danger and damage caused by overweight vehicles. The authors reveal that the current practice of applying liability to the driver and/or operator is not conducive to achieving compliance across the haulage industry. They indicate that the road transport industry is "generally in favor" of taking the problem-solving approach to enforcement which involves targeting carriers with a history of non-compliance.
- URS (2005, pp. 2-3, 51) develop a statewide commercial vehicle compliance strategic plan for Minnesota. The report indicates that achieving truck weight compliance is complex and requires more than enforcement (p. 2). The authors recommend establishing a network of virtual WIM stations to measure compliance and use Civil Weight Enforcement to help target enforcement efforts (p. 3). Minnesota uses Civil Weight Enforcement (part of relevant evidence enforcement) to target repeat weight violators (p. 51). This allows enforcement officers to use virtual WIM stations to identify habitual offenders and use this information to visit their premises and issue a civil citation (up to $10,000 fine).

The study indicates that weight violators are rarely caught at fixed weigh scales and recommends installing virtual weigh stations (VWSs) as a more effective approach. The study provides considerations for implementing VWSs as follows (p. 48):

- Roads with volumes greater than 500 vehicles per day
- Mainline roads in front of fixed weigh scales
- Primary, known by-pass routes for fixed weigh stations
- Ramp sorters at fixed weigh stations
- Trunk highways with substantial truck volumes
- Highways with high bulk commodity movements (*e.g.,* agriculture)
- Highways with one or more vulnerable bridge structures
- Newly rehabilitated roadways with significant truck volumes

The study describes what a performance-based approach to enforcement would involve and makes the distinction between inputs, outputs, and outcomes (*i.e.,* performance). The authors list primary reasons for using performance measures as follows (p. 57):

- Refining operational procedures
- Supporting investment decisions
- Prioritizing projects
- Providing information for outreach efforts
- Responding to legislative inquiries
- Providing input for organizational changes

The study identifies the following measures for inputs, outputs, and outcomes (p. 56):

- Input performance measures:
    - Number of scale facilities
    - Number of road miles covered by enforcement
    - Number of troopers and inspectors
    - Number of heavy VMT
    - Annual tons of overweight livery
    - Percentage of vehicles with permits

- Output performance measures:
    - Number of stops per hour worked
    - Number of inspections per day
    - Number of citations issued
    - Number of inspections per million commercial vehicle operator miles driven

- Outcome performance measures (measured for each link and summarized for the entire system)
    - Percentage of vehicles over legal gross
    - Percentage of vehicles over legal axle loads
    - Dollars saved from reduced pavement damage
    - Dollars saved from reduced bridge damage
    - Percent of vehicles operating legally
    - Number of citations issued versus number of vehicles inspected (calculated separately for roadside, mobile, and fixed scale inspections)

The study also provides examples of existing data sources that can be used to calculate performance measures (p. 58):

- Vehicle classification sites
- Traffic volume counters
- WIM scales
- Relevant evidence data
- Pavement ratings
- Bridge sufficiency ratings
- Safety data

Examples of applications of performance measures (p. 58) include the following:

- VWSs can be used to identify repeat offenders and target enforcement accordingly. Historical data could be compared to see if targeted violators are becoming more compliant due to targeted enforcement and the application of VWSs in this manner.
- Bridge vulnerability indices could be developed that prioritize targeted enforcement schedules by identifying bridge structures with low sufficiency ratings and low compliance rates on associated roads.
- Pavement vulnerability indices could be developed in a similar way to bridge vulnerability indices.
- Hourly violation rate tables could be developed that determine which hours are most likely to have overweight trucks; this information would support targeted enforcement.

• Leyden *et al.* (2004) describe Australian approaches to heavy vehicle accreditation and compliance. The authors recall that in 1997 the Australian Transport Ministers approved a voluntary accreditation system (National Heavy Vehicle Accreditation Scheme, NHVAS) where operators who apply for accreditation must have systems and procedures in place that will provide evidence of compliance. Accredited operators are subject to fewer roadside inspections and are instead subject to an ongoing audit regimen to ensure compliance is being maintained (p. 3). The authors state that adopting accreditation systems and providing various benefits to accredited operators (*e.g.*, higher weight limits, broader access to certain road networks) can serve as a powerful mechanism for compliance but also increase the efforts of regulators and the documentation they must keep to respond to legal challenges by operators who have been denied accreditation (p. 3). They also briefly describe the chain of responsibility concept and explain that any entity that exercises control over any of the following activities are subject to joint and several liability for overloading trucks (p. 6):
  - Consigning
  - Loading
  - Carrying
  - Driving
  - Receiving

Under this enforcement and compliance approach, violators (*e.g.,* consignors, carriers, receivers, etc.) must demonstrate that they took reasonable steps to avoid breaching weight limits or that they neither knew nor reasonably ought to have known of the breach. This encourages the installation of documentation systems to achieve and demonstrate compliance. The law also allows senior officers of a company (*e.g.*, director, manager) to be punished for committing a road law offence or if they encourage a truck to operate overweight (p. 6).

Australia created three categories of weight violations (pp. 6-7):

- Minor (up to five percent above legal limit)
- Substantial (up to 20 percent above legal limit)
- Severe (above 20 percent of the legal limit)

Australia also created a hierarchy of sanctions that provided flexibility and options for disciplining violators. This recognized that conventional fines may not be a deterrent for all parties in a logistics chain. Following is the hierarchy of sanctions in order from least punitive to most, where the first three are administrative sanctions and penalties and the remaining are court sanctions and penalties (p. 8):

- Improvement notice
- Formal warning
- Infringement notice
- Fine
- Commercial benefits penalty
- Supervisory intervention orders
- Orders affecting licenses and registration
- Prohibition orders

Australian law also allows the courts to issue a compensation order to an offender which compensates the road authority for loss or damage to any road infrastructure caused by the offense (p. 8).

The authors find that enforcing the chain of responsibility has led to significant improvements in documenting heavy loads, and that this documentation helps audit the evidence produced by accredited carriers. Australia is also finding that more shippers and receivers are including a requirement to be accredited into their service contracts to help mitigate their risk under the chain of responsibility (p. 9).

- Johnstone (2002, pp. 24, 25, 31) notes that road transport regulation, including truck size and weight regulation, has historically necessitated ensuring regulatory compliance with prescriptive requirements. On-road enforcement directed at drivers and operators has been the primary instrument used to achieve compliance with these regulations. This approach has been criticized because it ignores the responsibility of other parties within the logistics supply chain for a non-compliant event and it has applied a penalty structure inadequate for deterring non-compliant behaviour. In Australia, this criticism has led to the adoption of the chain of responsibility principle in which all parties within the trucking contractual chain have some duty to ensure compliance (including compliance with truck size and weight regulations). From a legal perspective, this duty must be established through a causal nexus between each party's activities and a non-compliant event.

- McIntyre (2002, pp. 53-55, 60-64) describes the (Australia) National Road Transport Commission's (NRTC) approach to enhancing a compliance culture. The author asserts that a "nationally consistent, well-targeted approach to enforcement is an important component of the Commission's strategic framework for compliance reforms." However, conventional (sanctions-based) enforcement is considered only one of a number of additional strategies needed to create a sustainable compliance culture for the trucking industry. Additional strategies, include:
  - Privileges and incentives-based strategies such as accreditation-based schemes;
  - Training of enforcement officers and industry;
  - Education and communication strategies;
  - Monitoring of enforcement effectiveness; and
  - Ongoing research to ensure programs adjust to technological, societal, and legal developments.

  A combination of approaches enables a more proactive (rather than reactive) means of achieving compliance. The author cites the following reasons why a reactive, enforcement-oriented response is insufficient:
  - "The effectiveness of enforcement-based strategies to modify road user behaviour is dependent on there being a perception that there is a real possibility that breaches will be detected. However, there are simply not enough policing resources to cover the whole road network, and the chance of apprehension at any one time is low.
  - Fines, no matter how high, will not have a sufficiently deterrent effect when the chance of detection is slight but the potential profits from offending are high.
  - Targeting only the driver and owner of heavy vehicles (the 'soft' enforcement options) will not deter the many 'off-road' parties who play a significant role in breaching the road laws."

  Australia's NRTC (as of 2002) proposed a reformed legislative approach to address these issues. Specifically, the legislation incorporates the chain of responsibility principle (including the parties involved in consigning, loading, carrying, driving, receiving, and packing) and the requisite enforcement powers to support it (such as compliance audits and the legal acceptability of various types of evidence). In addition, it provides a risk-based categorization of offences to account for varying severity and to enable distinctions between unintentional offences and those committed for commercial gain, between individuals and corporate bodies, and between first time and habitual offenders. The reforms also adjusted penalty structures.

- McKeachie and McCrae (2002, p. 116) describe the various elements of the "enforcement pyramid," which depicts a series of progressively more aggressive enforcement tools (moving from bottom to top), all of which are directed at achieving regulatory compliance (though not applicable only to the trucking industry). Starting at the base, the pyramid includes: persuasion and education, administrative penalties, civil penalties, criminal penalties, suspension, and revocation.

- USDOT (2000, p. VII-12) identifies the use of relevant evidence laws as one option to improve size and weight enforcement programs. Citing Minnesota as an example, the report indicates that bills of lading, weight tickets, and other relevant documents could be used as legal evidence to establish an overweight violation. Enforcement occurs through an audit of shipper or freight forwarder files, with legal action possible against the driver, shipper, owner, or lessee. While the use of relevant evidence laws was successful in Minnesota, pilot programs in the 1990s in four other states (Iowa, Louisiana, Mississippi, and Montana) were unsuccessful because of industry opposition to the required legislative support. The report identifies the administrative system used in Georgia to process weight citations as an alternative to the court process.

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