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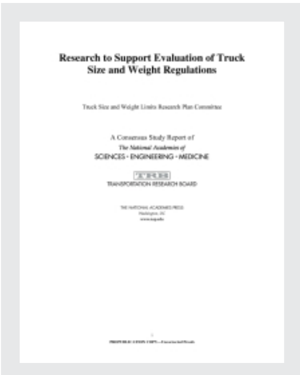
Research to Support Evaluation of Truck Size and Weight Regulations

Research to Improve Estimates of Impacts of Changes in Truck Size and Weight Regulations

DETAILS

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Research to Support Evaluation of Truck Size and Weight Regulations

Truck Size and Weight Limits Research Plan Committee

A Consensus Study Report of

The National Academies of

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PREFACE

The Transportation Research Board formed the Truck Size and Weight Limits Research Plan Committee to specify a program of research to reduce uncertainties in estimates of the effects of changes in the regulations that limit the sizes and weights of trucks. The study was sponsored by the Federal Highway Administration (FHWA), U.S. Department of Transportation.

The committee included members with expertise in highway safety research, bridge and pavement engineering, motor vehicle engineering, highway administration, law enforcement, and transportation economics. As part of its study, it organized a series of public webinars at which invited experts offered comments on research priorities and methods in the areas of pavement and bridge engineering, highway safety, highway regulatory enforcement, and freight transportation modeling. The webinar participants are listed in Appendix B. In addition, the committee heard presentations at its meetings from Chandra Bondzie, Gene McHale, Thomas Saad, and Robert Zobel, FHWA; John Gray, Association of American Railroads; and Mark Burton, University of Tennessee.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. The committee thanks the following individuals for their review of this report: Michael Belzer, Wayne State University, Detroit; Judith Corley-Lay, Michigan State University, Lansing; Lidia Kostyniuk, University of Michigan, Ann Arbor; Gerald McCullough, University of Minnesota, St. Paul; Hani Nassif, Rutgers, State University of New Jersey, Piscataway; Jonathan Regehr, University of Manitoba, Winnipeg; and Bernard Robertson, BIR1, LLC, Bloomfield Hills, Michigan.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft before its release. The review of this report was overseen by Chris T. Hendrickson (National Academy of Engineering), Carnegie Mellon University (emeritus); and Susan Hanson (National Academy of Sciences), Clark University (emerita), Worcester, Massachusetts. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies. Joseph R. Morris managed the study, edited the report, and drafted sections of the report under the guidance of the committee and the supervision of Thomas Menzies, Acting Director, Consensus and Advisory Studies Division. Stephanie Seki prepared literature reviews in support of the committee. Karen Febey managed the report review process. Amelia Mathis and Anusha Jayasinghe assisted with meeting arrangements and communications with committee members.

CONTENTS

SUMMARY

The U.S. Department of Transportation (USDOT) completed its *Comprehensive Truck Size and Weight Limits Study* in 2016, responding to a directive of Congress for a study to compare the impacts of truck traffic operating under present federal size and weight limits with the impacts if trucks exceeding present limits were allowed to operate. The report recommended that a program of research be undertaken to overcome limitations in data and in models of impacts that had hindered the study. USDOT subsequently asked TRB to convene a committee to develop a plan for a research program to reduce uncertainties in estimates of the impacts of changes in truck size and weight limits.

The TRB Truck Size and Weight Limits Research Plan Committee prepared a first report that identified candidate topics in five categories of impacts of changes in size and weight limits (safety, bridges, pavements, enforcement of limits, and shares of freight transported by truck and other modes) for inclusion in a research plan, in addition to topics addressing the structure and methods of evaluating size and weight regulations.

This second report presents the committee's research plan. The committee has defined a program of 27 research projects. For each project, the report provides a problem statement identifying the product, relationship to the overall objective of evaluating truck size and weight regulations, possible research approaches, and anticipated duration and cost. The program is selective: it includes projects on the categories of impact for which USDOT requested guidance and certain additional topics, but does not include research on categories of impact for which estimates have not been critical sources of uncertainty in past evaluations of size and weight regulations.

The committee grouped the projects in three categories. Projects included in one of the seven core research tracks identified below have a good probability of producing useful results within a practical time period and budget and would significantly contribute to reducing uncertainty in truck size and weight limit evaluations. The second category, projects that may be deferred, would have value, but would be less critical than the projects in the core research tracks in reducing uncertainties or would be of

long duration. A third category of projects for consideration would have a relatively high risk of producing inconclusive results or would be especially expensive and complex.

The core research tracks defined by the committee (each corresponding to a research problem statement or to a series of problem statements) are the following:

- Development of a truck traffic, weight, and configuration database from nationwide weigh-in-motion installations and other sources.
- Development of a discrete continuous choice model, or suitable alternative, capable of estimating the effect of changes in truck size and weight regulations and other policies on shippers' and carriers' choices of freight mode, vehicle configuration, and shipment size.
- Development of pavement analysis methods for heavier axle limits, multiaxle groupings, and alternative tire and suspension types.
- Development of a comprehensive model of the relationship of bridge deterioration and service life to vehicle loads.
- Comparative evaluations of crash risks of alternative configurations by the case-control method.
- Development of protocols for evaluating the performance of configurations with simulation, track testing, and field trials.
- Measurement of relationships between frequency of overloads and enforcement methods and level of effort.

The core research tracks constitute a program of research that could meet the need for improved evaluation capabilities in the short term. The short-term goal would be to provide the capability to respond with the best available estimates to the kinds of proposals for changes in size and weight regulations that arise frequently at the federal and state levels. The full research program (to which the core research would contribute) would have the long-term goal of identifying opportunities for major improvements in performance of the highway freight transportation system with respect to safety, infrastructure cost, and productivity. As noted in several of the problem statements, progress on the core research tracks would be aided by awareness of current international research and regulatory practice.

In addition to the research problem statements, the report presents eight general conclusions of the committee on research needs and priorities:

- The value of research on truck size and weight regulations.
- Limitations of impact projections.
- The value of broadly applicable research.
- The importance of general purpose data programs.
- The need to match research to policy objectives.
- The value of tests and trials in evaluations of truck size and weight limits.
- Emerging technologies and truck size and weight regulations.
- Organizational needs and options.

The conclusions emphasize that improvements in models for projecting infrastructure, safety, and freight cost consequences of changes in limits will not guarantee the success of future truck size and weight policy studies. Future studies will be useful as guides for decisions only if policy objectives and practical policy options are clearly defined, the analysis is logically structured to reveal the most promising policies, and uncertainties are properly characterized.

1

INTRODUCTION

USDOT delivered to Congress the final report of its Comprehensive Truck Size and Weight Limits Study (FHWA 2016a) in 2016, according to the requirements of Section 32801 of the Moving Ahead for Progress in the 21st Century Act (MAP-21) of 2012. The act called for a study to compare the impacts of truck traffic operating under present federal regulations with the impacts if truck configurations exceeding present size and weight limits were allowed to operate, with respect to safety, infrastructure, cost responsibilities, fuel efficiency, freight transportation costs, the environment, truck traffic volumes, and shares of freight traffic carried by trucks and other freight modes. The act also required an evaluation of the frequency of violations of federal truck size and weight regulations and the cost and effectiveness of enforcement. The 2016 study was the most recent of a series of federal evaluations of truck size and weight regulations conducted over the past several decades (see Box 1).

In its report to Congress, USDOT observed that "the analytical work revealed very significant data limitations that severely hampered efforts to conclusively study the effects of the size and weight of various truck configurations" (FHWA 2016a, 17) and recommended that a program of research be undertaken to overcome these limitations (FHWA 2016a, 21): "To make a genuine, measurable improvement in the knowledge needed for these study areas, a more robust study effort should start with the design of a research program that can identify the areas, mechanisms, and practices needed to establish new data sets and models to advance the state of practice."

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BOX 1
Federal Truck Size and Weight Studies, 1941–2016

Interstate Commerce Commission (1941): *Federal Regulation of the Sizes and Weights of Motor Vehicles*
U.S. Department of Commerce (1964): *Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-aid Systems*
USDOT (1968): *Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights*
USDOT (1981): *An Investigation of Truck Size and Weight Limits*
USDOT (2000a): *Comprehensive Truck Size and Weight Study*
USDOT (2004): *Western Uniformity Scenario Analysis*
FHWA (2016a): *Comprehensive Truck Size and Weight Limits Study*

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In 2017, the FHWA Office of Freight Management and Operations asked TRB to develop a plan for a research program as recommended in the 2016 USDOT final report. In response, TRB organized the Truck Size and Weight Limits Research Plan Committee, charged with the following task:

This project will develop and recommend a research roadmap to address gaps and uncertainties in estimating the impacts of changes in truck size and weight limits. Specific research projects, estimated costs, and timelines will be recommended in the areas of safety, compliance/enforcement, modal shift, bridges, and pavements. The recommendations will include efficient means of collecting data essential to estimating the impacts of larger and heavier trucks in these five areas on national, state, and local roads.

The first report of the committee (TRB 2018) summarized research recommendations of past truck size and weight limit studies and listed research topics under consideration for inclusion in the committee's research plan in each of the five categories of impact identified in the task statement (safety, enforcement, modal shift, bridges, and pavements) as well as research topics on methods to evaluate alternative truck size and weight regulatory structures. The first report also discussed the criteria that the committee would take into account in deciding the priority of topics for inclusion in its research plan.

This second report presents the committee's research plan (that is, the research roadmap to which the task statement refers). The committee has defined a program of coordinated research projects, aimed at reducing the major sources of uncertainty in past projections of the consequences of proposed changes in truck size and weight limits. For each project, the report provides a problem statement identifying the product, relationship to the overall problem of evaluating truck size and weight regulations, possible research approaches, anticipated duration and cost, and necessary participants in the research.

The research program is selective; it includes projects on the categories of impact identified in the statement of task and certain additional topics that the committee concluded require attention, but does not include research on all significant categories of impact of changes in the limits. In particular, research projects on environmental, energy, and traffic congestion impacts have not been included. These impacts may be important considerations in future decisions on the regulations. . However, their estimates have not been critical sources of uncertainty in past size and weight studies because the uncertainty in projections of environmental, energy, and congestion impacts arises primarily from uncertainty in the projected change in truck traffic volume caused by a change in regulations. Research to develop improved methods of projecting truck traffic changes is included in the research roadmap. A 1996 TRB committee report demonstrated methods for estimating social costs of freight transportation and illustrated the relative magnitudes of public and private costs in selected cases (TRB 1996).

Even major improvements in models for projecting infrastructure, safety, and freight cost consequences of changes in limits will not guarantee the success of future truck size and weight policy studies. Future studies will be useful as guides for decisions only if policy objectives and practical policy options are clearly defined, the analysis is logically structured to reveal the most promising policies, and uncertainties are properly characterized. The recommendations of the TRB committee that reviewed the technical analysis of the 2016 USDOT size and weight study emphasized not only the importance of improving impact models, but also the importance of providing a logical structure that clarifies choices for decision makers. For example, the committee noted the need to present all cost and benefit estimates in consistent, comparable units of measure; the need to estimate system-wide safety impacts (the net effect of changes in truck characteristics and truck traffic volume); and the need to evaluate alternative regulations and not simply alternative vehicles (TRB 2015, 10–21).

Designing the most useful structure for any future comprehensive truck size and weight policy study (including the definitions of objectives, policy alternatives, and decision rules) is itself a problem requiring research. The ideal structure would be as an economic optimization problem: the analysis would identify the range of practical options for government actions, including size and weight limits and related road management practices (user fees, enforcement, road design, and asset management), project comprehensive public and private costs and benefits, and select the package of policies that promised the greatest net benefit for the public. The committee has included research topics to develop an analysis framework for truck size and weight policy studies in the roadmap.

Sources for the Roadmap

To identify the major sources of uncertainties in projections of impacts of changing truck size and weight limits, the committee reviewed the results of the USDOT truck size and weight studies of 2016, 2000, and 1981 and the conclusions these studies reached about deficiencies in data and models available for the analyses. The 2016 USDOT study report identifies the deficiencies in data and models that the study encountered and recommends numerous improvements (FHWA 2016a, 21–25).

The committee also identified research requirements arising from recent developments not considered in the 2016 USDOT study or in the earlier studies, in particular, the implications of truck platooning (operation of two or more trucks in a convoy with close spacing maintained by an advanced driver assistance system) and other information technology advances applied to truck operations that may cause future truck performance and patterns of use to diverge from historical experience.

Sources on the state of knowledge of modeling impacts and on possible research approaches included the research undertaken by USDOT in support of its 2016 study; research recommendations of past TRB committees, including the committee that conducted a review of the technical analyses of the USDOT 2016 study (TRB 2015); and a series of public webinars at which experts invited by the committee offered comments on research priorities and methods in each of the impact areas. The webinar programs appear in Appendix B.

The 2002 report of the TRB Committee for the Study of the Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles (TRB 2002) was an important resource for the present committee. The 2002 report was prepared in response to a congressional directive for a study of the federal regulation of truck sizes and weights and for recommendations on revisions. Its conclusions were based on a detailed review and assessment of the major prior studies of size and weight limits by the federal government, TRB committees, and others. The 2002 committee’s conclusions about uncertainties and errors in past evaluations, the method of estimating effects of changes in truck size and weight limits on bridge costs, the design of trials to evaluate new truck configurations, and the appropriate structure and objectives of truck size and weight studies are cited in later sections of this report.

The present committee's first report summarizes recommendations related to research and data requirements from the USDOT studies and from past TRB committee evaluations of truck size and weight limits (TRB 2018, 5–15). It also identifies candidate research topics for the roadmap, compiled from the sources previously described, in each of the five impact areas of pavement, bridges, safety, enforcement, and mode choice, together with a list of crosscutting topics (TRB 2018, 15–24).

The first report also describes six criteria that the committee has considered in setting priorities among the inventory of research and data needs and in defining the appropriate roles of USDOT and other possible participants in research and data collection (TRB 2018, 25–29):

- Relative magnitudes of the potential cost changes caused by a change in limits.
- Degree of uncertainty in present estimates.
- Likelihood that research could make progress.
- Public and interest group concerns.
- Potential value of research results for general highway management applications.
- Assumed objectives of the regulatory changes under consideration.

Each research problem statement in this report includes an examination of the priority of the topic, with reference to these criteria.

Structure of Truck Size and Weight Limit Studies

The committee recognized that the research program must be designed to fit the needs of the intended applications. Therefore, it examined the methods of past truck size and weight limits policy studies to understand the information requirements of these studies.

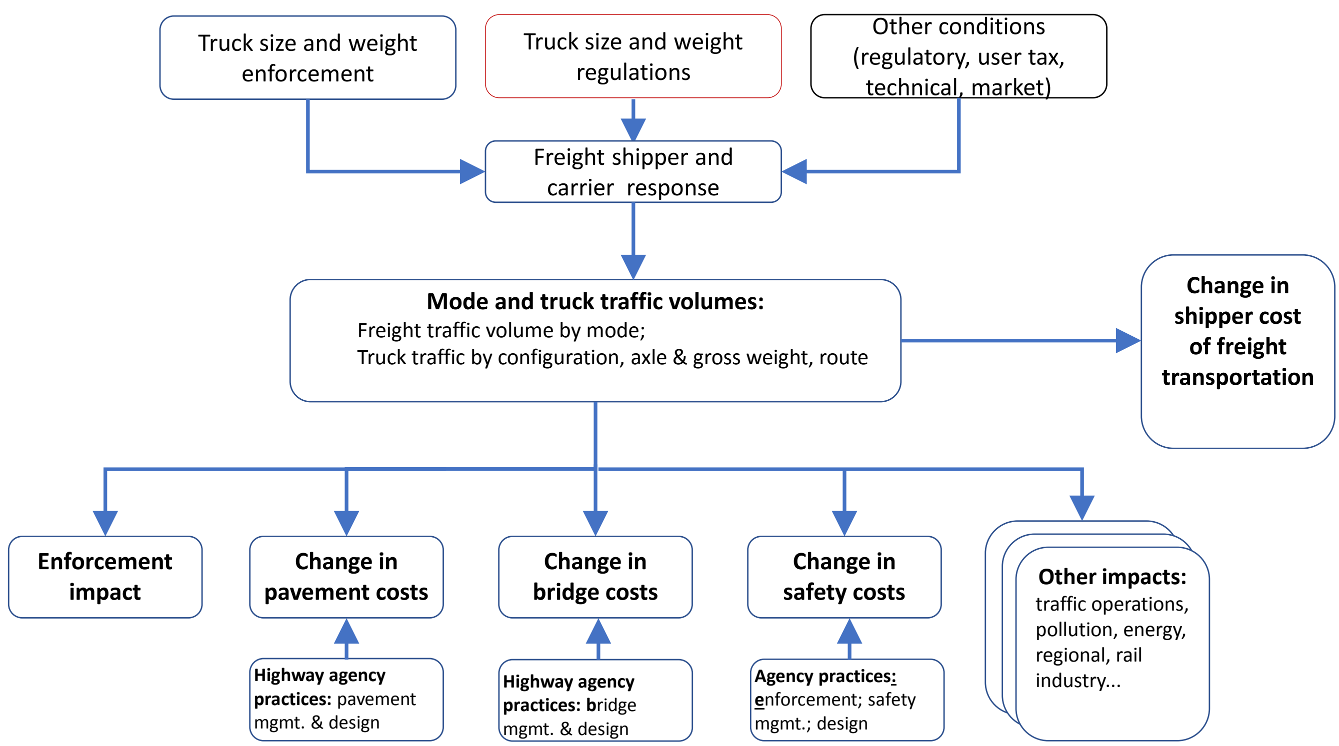
Nearly all past U.S. studies followed a similar conceptual framework for evaluating proposed changes in size and weight limits. The steps in this conventional method (see Figure 1.1) are as follows:

1. Specify a set of alternative regulatory scenarios (size and weight limits and related regulations such as route restrictions).

2. Project truck traffic volume and composition in each scenario.
3. Project changes in costs affected by the change in limits, including highway agency costs to construct and maintain roads and bridges; freight shipper and carrier costs; highway user costs, including congestion and crash risk; and other costs to the public such as pollution.
4. Assess certain other collateral effects of the change in limits, including rail industry impact and highway agency budget impact.
5. Recommend any changes in limits that the evaluation indicates would be beneficial, considering costs, benefits, practical constraints, and uncertainties. Some studies present results of the comparative analysis of regulatory alternatives without recommendations.

The committee's task statement is consistent with the needs of a truck size and weight study that follows this framework, that is, a prospective study that attempts to forecast changes in traffic and in costs from a change in limits. The five impact areas in the task statement are elements of the framework: mode choice, safety, pavement, bridges, and enforcement.

Figure 1.1 Structure of a truck size and weight policy evaluation.



The TRB Commercial Motor Vehicles committee (TRB 2002, 41–47) recommended two fundamental modifications to this conventional framework:

- Any future truck size and weight study should be structured as an evaluation of alternative policies for achieving a specified objective, rather than as an evaluation of alternative vehicles. The alternative policies considered would include not only changes in limits, but also coordinated changes in other highway management practices that affect the performance of highway freight transportation.
- In recognition of the unavoidable uncertainties in forecasts of the consequences of new regulations, evaluation of new regulations should include systematic monitoring of consequences whenever regulations are changed.

The steps in such an evaluation would be the following:

1. Define the specific policy objective that changes in regulations and practices would be intended to achieve in terms of increased public benefits from the highway freight transportation system.
2. Specify an initial package of policies aimed at the objective, including changes in truck size and weight limits and related policies, which could include changes in safety regulations, user fees, asset management, pavement and bridge design and rehabilitation methods, and enforcement.
3. Project the private-sector response and public costs and benefits of the policy package according to the conventional method shown in Figure 1.1.
4. Compare the projected outcome with the objective. If the outcome falls short, revise the policy package to try to overcome the obstacles that the evaluation has revealed and repeat the evaluation with the revised policy package. Iterate to identify the best opportunities for achieving the objective.
5. If regulatory changes are adopted, systematically monitor the consequences and identify adjustments to regulations and practices needed to bring the outcome closer to the objective.

Past truck size and weight studies acknowledged the potential value of coordinating size and weight regulations with other highway management practices to achieve an objective of improved system performance. For example:

- The 1981 and 2000 USDOT truck size and weight studies (USDOT 1981, 2000a) were conducted in conjunction with highway cost allocation studies, in recognition of the need to align user fees with size and weight limits. The USDOT studies did not project how changes in fees would affect the consequences of changing the limits, but such alignment could strongly influence truck operators' equipment choices (Small et al. 1989, 55–56).
- The TRB committee study of the Turner Proposal (TRB 1990b) (a proposal to allow operation of higher gross weight trucks with lower maximum axle weight limits) sought changes in size and weight limits and other practices to attain a defined performance objective, the simultaneous reduction of shippers' freight costs and infrastructure costs. The committee could not identify such a win–win outcome, but proposed a coordinated package of size and weight, safety, user fee, enforcement, and asset management policies aimed at increasing public benefits.
- In the 1981 USDOT study, "Scenario K" was a similar attempt to specify limits that would increase freight productivity and reduce infrastructure costs (USDOT 1981, II-7–II-8).
- The 1964 U.S. Department of Commerce (DOC) study recommended changes in limits coupled with the imposition of performance standards for engine power, braking, and the linkages between combination units (DOC 1964, 5).

As hypothetical examples, the objective of a future truck size and weight study might be defined as designing a package of truck user fees and size and weight limits that would allow increased freight productivity and provide the revenue needed for infrastructure upgrades to accommodate more productive vehicles, or as designing a package that reduced infrastructure costs without degrading freight productivity or safety. Such proposals start with the premise that present regulations and practices are far from the optimum and can be improved.

With respect to the committee's task, the framework that future truck size and weight studies will adopt is relevant because it dictates research needs. If a framework of seeking policies that increase public benefits is adopted, models capable of evaluating coordinated policies will be needed, including:

- Models of mode and vehicle choice in the private sector that are able to represent the effect of alternative highway user fee and tax structures on the use of existing and new configurations.
- Methods to project the effect of alternative enforcement practices on weight distributions.
- Models of pavement- and bridge-related costs that are able to represent the consequences of alternative highway agency asset management and weight enforcement practices.
- A method of projecting safety impact that is capable of representing the effect of vehicle performance standards on crash risk.

With few exceptions, past truck size and weight studies have not developed methods for these kinds of analyses.

Outline of the Report

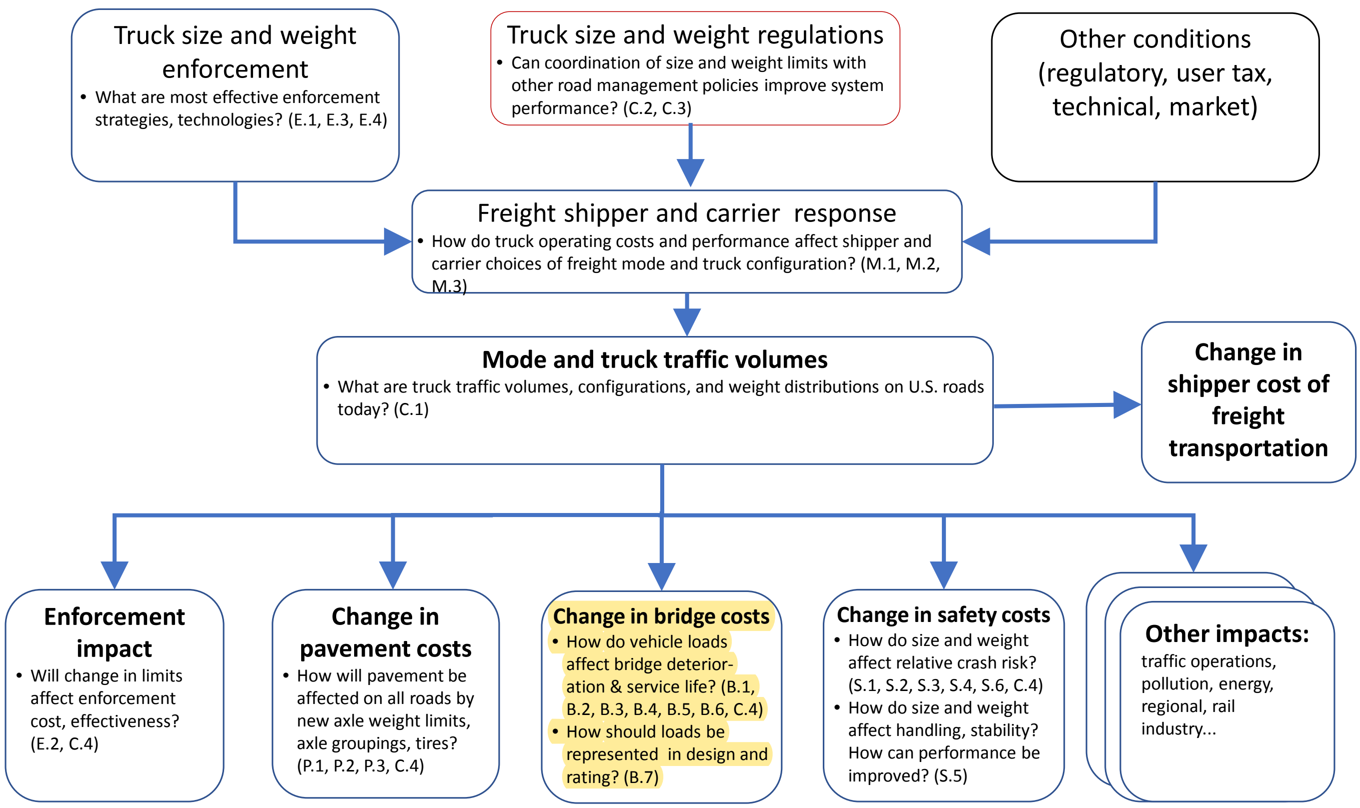
The first section to follow is a summary of the roadmap. The section after that presents conclusions of the committee about research needs, priorities, and the organization of future research. Appendix A contains research problem statements for the projects in the roadmap in the five impact areas of pavements, bridges, safety, enforcement, and mode choice as well as cross-cutting topics (topics relevant to all impact categories). The research problem statements in each impact area are preceded by a discussion of the motivation for the research, with respect to deficiencies of past estimates and the importance of the impact to the overall evaluation of alternative regulations. Appendix B contains the programs of the public webinars organized by the committee.

2

SUMMARY OF THE ROADMAP

The roadmap includes research problem statements outlining 27 research projects in six groups corresponding to the five categories of impact in the Statement of Task and one group of crosscutting topics (i.e., topics relevant to several or all impact categories) (see Table 2.1). The relation of roadmap projects to the structure of a conventional truck size and weight limits study is illustrated in Figure 2.1.

Figure 2.1 Relation of roadmap projects to the structure of a truck size and weight policy evaluation.



Problem Statements

The research problem statements follow a standard outline:

1. Title of the research topic.

2. Problem statement: A summary description of the problem to be solved, together with an explanation of how the problem relates to estimating the costs or benefits of changing truck size and weight limits.
3. Research objective: Specification of the desired research outcome or product (for example, a model, a methodology, a cost estimate).
4. Possible approaches: Outlines of one or more possible research approaches, to indicate the scope of the work and the resources needed.
5. Data requirements: Identification of existing data resources that the research may use and data that would be collected as part of the research.
6. Present status of research: Literature references to existing research that addresses the problem, to indicate the state of knowledge on the problem and to use as examples of possible research approaches. This also includes references to research on analogous problems that illustrates methods that may be applicable to the problem.
7. Estimated cost and duration of the research.
8. Priority: An assessment of the potential contribution of the research to reducing uncertainty about the likely consequences of changing truck size and weight limits. This assessment also notes potential broader applications of the research results in highway management and planning.

The outline is similar to that used for submitting research problems for consideration by the National Cooperative Highway Research Program (NCHRP).

For most of the research problems, it was not the intent of the committee to specify a single acceptable research method. The “Possible Approaches” section in each research problem statement is intended to clarify the content of the research proposed and to show that the research would be feasible. Investigators undertaking any of the problems would select the method. Selection of the method will depend on the funding available for a project: most problems could be addressed with any of a range of approaches, from simple methods with relatively low cost but more approximate results to more data-intensive methods with higher costs but possibly more credible results.

Within each impact area (pavement, bridges, safety, enforcement, and mode choice), the division of the research into discrete projects is to some extent arbitrary. The scope of each research problem statement could be conducted as a discrete project that would produce useful results. However, most problem statements also are components of a program or sequence of research projects. Completion of the program would achieve the greatest improvement in evaluations.

Research Cost, Duration, and Sequencing

The Statement of Task asks for estimated costs and timelines for the projects in the research roadmap. The cost and duration estimates in each research problem statement represent the judgment of committee members, based on their experience with similar projects. The committee did not carry out detailed cost estimates. In most cases, the cost of a project could vary over a wide range, with a larger budget allowing collection and analysis of a larger dataset and possibly more credible impact estimates.

An early start would be necessary for research problem statements C.1 (development of truck traffic, weight, and configuration data) and S.1 (enhancement of crash and exposure data for application in a research environment), which outline research to develop data required for several other roadmap projects. Within the bridge impacts area, problem statements B.2 and B.3 are for research to develop physical models of the effects of trucks on bridges; these models would then be applied in the research of problem statements B.4 and B.5 to develop methods of estimating life-cycle cost effects of changes in truck sizes and weights. Similarly, in the pavement impacts area, problem statement P.1 is to develop a physical model, and problem statement P.2 would then apply the model in developing a method for estimating life-cycle cost.

Priorities

The projects in the roadmap are grouped in three priority categories:

- Projects included in one of the seven core research tracks defined below: These projects could be started immediately, have a good probability of producing useful results within a practical time period and budget, and would contribute to the core research program outlined below for reducing uncertainty in truck size and weight limit evaluations.
- Projects that may be deferred: The project would be feasible and have value, but is less critical than the projects in the core research tracks for reducing uncertainties in truck size and weight limit evaluations or would be of long duration (for example, projects requiring long-term performance data that are not yet available).
- Projects for consideration: These projects would have a relatively high risk of producing inconclusive results, or would be especially expensive and complex. Some of these would have greater probability of success after successful completion of projects in the first two categories. These projects should be considered in the context of FHWA's overall research priorities.

The category to which a project is assigned does not necessarily reflect the ultimate value of the research if the project could be successfully conducted.

Core Research Tracks

The committee understands that USDOT has an interest in expeditiously gaining improvements in its ability to evaluate truck size and weight limit policy proposals. At the same time, USDOT may choose to undertake a long-term research program to fully meet analysis and information needs for managing the highway freight transportation system. The short-term research program goal would be to provide the capability to respond with the best available impact estimates to the kinds of proposals that arise frequently at the federal and state levels for changes in size and weight regulations. The long-term goal would be to seek major improvements in performance with respect to safety, infrastructure cost, and productivity.

Attaining fundamental improvement in USDOT's capabilities to project the effects of changes in truck size and weight regulations will depend largely on improvements in state-maintained data systems, including asset management systems, crash records, and traffic data systems. Improving these systems historically has been a slow process and one outside of direct federal control. Improvements in USDOT capabilities in the short term (for example, in the next 3 to 5 years) will be constrained by the limitations of the existing data systems. Regularly collected data can be supplemented with ad hoc data collection in special studies (as proposed in the problem statements for studies of bridge impacts and comparative crash risk). The applicability of results of special studies to the U.S. road system's diversity of infrastructure and traffic conditions will remain a source of uncertainty.

The committee has defined a core program that could meet the need for improved evaluation capabilities in the short term. The core program is a subset of all the projects in the roadmap that would constitute a practical package of coordinated research that could be completed within 4 to 6 years for $4,000,000 to $6,000,000. The intent of the core program would be to provide the greatest reduction in uncertainty achievable within specified time and budget constraints. The research projects would have good probability of success, and results of most of the projects would have value in applications beyond truck size and weight limit evaluations.

The core program includes seven core research tracks. Each track corresponds to one research problem statement or to a series of problem statements. The core research tracks are as follows:

- Truck traffic, weight, and configuration database compiled from nationwide weigh-in-motion (WIM) installations and other sources.
- Discrete-continuous choice model, or suitable alternative, capable of estimating the effect of changes in truck size and weight regulations and other policies on shippers' and carriers' choices of freight mode, vehicle configuration, and shipment size.
- Pavement analysis methods for heavier axle limits, multiaxle groupings, and alternative tire and suspension types.

- Comprehensive model of the relationship of bridge deterioration and service life to vehicle loads.
- Comparative evaluations of crash risks of alternative configurations using the case-control method.
- Protocols for evaluating the performance of configurations using simulation, track testing, and road trials.
- Measurement of relationships between frequency of overloads and enforcement level of effort and methods.

The core research tracks would be a reasonable starting point on the extensive program of research in the full roadmap. Exclusion of a project from the core is not meant to imply that the project necessarily would be of less value or less feasible than the projects included. Selection of the first projects in a future research program will be a USDOT decision that will depend on department-wide research priorities and analysis needs.

The seven core research tracks are described in the following section (with reference to the detailed definitions in the research problem statements) and summarized in Table 2.2.

Truck Traffic, Weight, and Configuration Database from Nationwide WIM Data and Other Sources (Problem Statement C.1)

Using the WIM and vehicle classification data that are now collected by the states and compiled by FHWA, this project would develop procedures for data editing and quality control and methods for appropriate weighting of observations to produce a credible base-year estimate of truck traffic volumes and weight spectra for the U.S. road system. The research would also provide the truck weight data needed for infrastructure impact modeling research projects in the roadmap.

Baseline estimates of traffic volumes and axle-weight, gross-weight, and configuration-type distributions are necessary in estimating infrastructure cost, safety, freight cost, and mode share impacts of changes in truck size limits and developing models of the relation of loads to bridge and pavement costs.

More reliable truck weight and configuration data could be produced by establishing a network of WIM installations designed according to scientific sampling principles to meet the requirements of the intended research and management applications; however, creation of such a network would be a long-term project.

Model of Mode and Vehicle Choice (Problem Statements M.1 and M.2)

The research would develop a model for projecting the effect of changing size and weight limits on distribution of freight among modes (truck, rail, and possibly barge) and the distribution of truck freight among truck types. The model would be of the discrete-continuous choice type, or a suitable alternative, estimated econometrically from observations of shipper or carrier mode and vehicle choice decisions for individual shipments.

The costs and benefits of a change in size and weight limits will be driven by the effect of the change on the volume of truck freight traffic and on the distribution of truck types that carry the freight. If all costs and benefits were simply proportional to the volume of freight in the new vehicles, the magnitude of freight shifts might not be critical to regulatory decisions. However, the relationship depends on the impact category. For example, bridge costs, as conventionally estimated, are insensitive to the volume of traffic diverted to new vehicles. Safety and pavement costs of a limit change that allows higher capacity trucks are sensitive to the net effect on truck traffic volume of higher capacity per truck and the new freight attracted to the roads by lower costs.

In addition, a freight market model is required to evaluate the effect of coordinating truck user fees with size and weight limits.

The TRB committee that reviewed the technical analyses of the USDOT 2016 truck size and weight study identified shortcomings in the model FHWA now uses for projecting mode choice and concluded that a new method is needed (TRB 2015, 38–42). The present model is deterministic rather than stochastic; this structure tends to exaggerate the sensitivity of mode choice to changes in relative costs of modes (Abate et al. 2018). The method of the USDOT 2016 study uses averages derived from aggregate data in place of actual individual shipment characteristics as model inputs; this method does not yield credible projections (TRB 2015, 39–40).

Research nearing completion in the National Cooperative Freight Research Program (NCFRP) is expected to provide a suite of practical discrete-continuous choice models of mode choice (between truck and rail), by commodity, applicable to truck size and weight limit evaluations. Because of limitations in the available freight shipment data, the NCFRP models cannot be used to estimate how changes in the regulations would affect choices among truck configurations. Development of the vehicle choice component of the choice model would require new data collection.

The choice model would not replace all the components of the freight market impacts evaluation in the USDOT 2016 study; other models would be needed to project rail revenue impact and the route distribution of truck traffic. The choice model would provide a more credible method of projecting mode shares and the extent of use of new truck configurations.

Pavement Analysis Methods for Heavier Axle Limits, Multi-Axle Groupings, and Alternative Tire and Suspension Types (Problem Statement P.1)

This research would develop a pavement analysis framework that realistically simulates the impact of vehicles with maximum axle and gross weights, axle configurations, and lengths that differ from those in common use today on the actual pavements of the U.S. road system.

Pavement costs have not been a major source of uncertainty in past truck size and weight studies because the majority of regulatory alternatives evaluated did not involve changes in axle weight limits. If maximum axle weights remain unchanged, pavement cost changes will be modest, and existing models are adequate to project the effects. However, USDOT should have the capability to evaluate changes in axle weight limits, because it is unlikely that the present limits are optimum for economic highway operation in the long term. Existing pavement models are unreliable for projecting the effects of maximum axle weight substantially different from the present or multiaxle groupings and spacings that differ from present use.

Enhanced pavement models are also needed to evaluate opportunities to reduce pavement wear through tire configuration and advanced suspension designs and through control of vehicle spacing and tracking (wander) in truck platoons in future automated and connected operations.

Comprehensive Model of the Relationship of Bridge Deterioration and Service Life to Vehicle Loads (Problem Statements B.2 and B.3)

This project would assemble historical truck traffic and bridge condition data for a sample of bridges to validate or calibrate engineering models of the relationship of loads to rate of deterioration and to estimate statistical relationships between loads and deterioration. Past USDOT and TRB studies estimated that costs to correct structurally inadequate bridges would be the largest estimated cost of allowing substantially higher gross weight limits. However, the TRB Commercial Motor Vehicles committee (TRB 2002, 63–69) concluded that the method of estimating the effect of changes in truck weights on bridge costs in most past studies is logically flawed and has not produced life-cycle cost estimates useful for guiding decisions. Improved estimates require a model to link bridge deterioration and loss of service life to vehicle loads.

The research would use existing historical truck weight and bridge condition data. As an alternative, condition data would be collected specially for the research. The research could include use of new methods for improving the efficiency of bridge condition data collection, for example, lidar (light detection and ranging) technology. If a large database of historical bridge condition and truck traffic data is created, machine learning may be applicable to identify relationships of bridge condition and condition trend to bridge characteristics and truck load history. FHWA's Long-Term Bridge Performance Study could produce data better suited for modeling the effect of truck traffic on bridge performance.

Comparative Evaluations of Crash Risks by the Case-Control Method (Problem Statements S.1 and S.3)

This research would develop and demonstrate procedures for measuring relative crash risks of alternative truck types using the case-control study design, for application in evaluations of proposed changes in truck size and weight limits. A case-control study of the relative crash risk of alternative truck types monitors occurrences of truck crashes on a road system and subsequently, at the site of each crash and typically at the same time of day and on the same day of the week, collects data on the characteristics of all trucks in the traffic stream. Comparing trucks in crashes (the cases) to trucks in the traffic stream (the controls) reveals characteristics that are over- or under-represented among the crash-involved trucks.

The case-control method has less demanding data requirements than the alternative method of directly measuring crash involvement rates from systemwide crash records and estimates of vehicle miles of travel by truck type over a road system. The method produces estimates of relative risks rather than crash rates. Some critical variables that influence risks (for example, driver characteristics) can only be obtained if control vehicles are stopped and inspected. The method can only be applied to compare truck types that are in general use on the road system or that are taking part in a road trial.

Case-control studies are the method most likely to succeed in the short term in improving quantitative understanding of the relationship of truck configuration and weight to crash risk. The method has been demonstrated in studies by the Insurance Institute for Highway Safety (Teoh et al. 2017, Braver et al. 1997, Stein and Jones 1988). In the long term, improvements in traffic monitoring and in crash record systems will support useful direct measurements of crash rates.

Protocols for Evaluating Performance of Configurations with Simulation, Track Testing, and Road Trials (Problem Statements S.5 and C.4)

A research program to develop protocols for the use of vehicle performance simulation modeling, track testing, and trials in evaluations of truck size and weight limits would define performance measures; identify appropriate models; define test procedures; determine the scale, participation requirements, and data collection and analysis methods of trials; design an administrative structure; and finally conduct selected evaluations as a demonstration of the procedures.

Predictions made in past truck size and weight limit studies of the safety consequences of changing the limits have most commonly relied on comparative crash rate estimates derived from historical data. However, changes in federal limits are likely to lead to use of new vehicles with little record of previous use. Computer simulation modeling of vehicle dynamic behavior and measurement of vehicle performance on a test track are means of comparing alternative vehicles with respect to performance characteristics that are believed to be linked to crash risk (for example, performance during braking, off-tracking in turns, and behavior during sudden steering maneuvers). Vehicle dynamic behavior is also linked to pavement and bridge impacts. Simulation and testing can guide performance-based regulations that require trucks to meet minimum standards with respect to handling, stability, and infrastructure interaction.

Some past U.S. truck size and weight studies have included vehicle performance simulation modeling and track testing, but the results have seldom been central to the studies' conclusions and recommendations. Sophisticated simulation models are available for this purpose, and regulatory programs in other countries (including Canada [Woodrooffe et al. 2010] and Australia [NTC 2008]) provide examples of the application of such evaluations. Road trials would be a final evaluation stage following simulation and track testing. A trial would evaluate performance of a new configuration in commercial use on a limited scale and under controlled conditions.

Relationship Between Frequency of Overloads and Enforcement Methods and Level of Effort (Problem Statement E.1)

This research would determine the relationship between the frequency of overloads on states' highways and characteristics of the states' truck weight enforcement programs, including level of effort, methods, and legal provisions. Enforcement effectiveness would be measured from weight data developed in the first core research track previously highlighted.

Results would be applicable for assessing the impact of a change in size and weight regulations on enforcement cost and effectiveness and for coordinating size and weight regulations with enforcement practices. The results also would allow truck size and weight enforcement agencies to more accurately predict the outcomes of resource investments and guide improvements in the cost-effectiveness of enforcement, regardless of whether size and weight limits are changed.

Table 2.1 Problem Statement Topics in the Research Roadmap

Key:
Priority:

- Projects included in one of the seven core research tracks: These projects could be started immediately, have a good probability of producing useful results within a practical time period and budget, and would contribute to the core research program for reducing uncertainty in truck size and weight limit evaluations. Most also would have broader value (beyond truck size and weight limit evaluations).
- Project that may be deferred: These projects would be feasible and would have value, but are less critical for reducing uncertainties in truck size and weight limit evaluations or would be of long duration (e.g., projects requiring long-term performance data that are not yet available).
- Projects for consideration: These projects would have a relatively high risk of producing inconclusive results or would be especially expensive and complex. FHWA should consider the research in the context of its overall research priorities.

Broader Applications: Value of the research for applications in highway management and planning, beyond evaluation of changes in truck size and weight limits.

Coordination Requirements: Certain projects would be most practically conducted in conjunction with related research by USDOT or state agencies.

Project	**Priority**	**Broader Applications**	**Coordination Requirements**
Pavement Research			
P.1 Realistic assessment of impact of a change in truck size and weight on the condition of pavements of the road network	Core track project	Identify opportunities to control pavement costs through modification of axle configurations, tires, suspensions	
P.2 Method of estimating the effects of a change in truck size and weight limits on highway agency pavement costs and highway user costs	May be deferred		
P.3 Effect of truck platooning on pavement performance and costs and methods to control the effect	May be deferred	Identify opportunities to mitigate pavement cost through adjustments to spacing or tracking in platoons	Truck component manufacturers, truck operators
Bridge Research			
B.1 Compilation of information from highway agencies on costs and decision criteria for bridge repair, rehab, strengthening, and replacement	For consideration	Provide benchmark for agency bridge management practices	State and local highway agencies
B.2 Model of effect of wheel loads on bridge deck deterioration and service life, supported by field performance data	Core track project	Model may aid bridge management and deck design	State and local highway agencies
B.3 Models of effect of changes in size and weight on common bridge types, including effect on service life of load-carrying members	Core track project	Of value for general highway agency bridge management	State and local highway agencies
B.4 Method for estimating effect of changes in size and weight limits on life-cycle costs of bridge decks	May be deferred		

B.5 Method for estimating the effect on bridge life-cycle cost of the change in deterioration and service life caused by changes in size and weight limits	May be deferred		
B.6 Development of a replacement for the "Formula B" provision in federal law that more appropriately controls weights of short, heavy vehicles	May be deferred		
B.7 Development of a revised deck design load and permit design load and calibration of load factors for both	May be deferred	Revised design loads are needed to accommodate present actual loads	
Safety Research			
S.1 Enhancement of crash and exposure data for application in a research environment	Core track project		State and local highway and highway safety agencies
S.2 Route-based or network-based comparative evaluations of safety performance of truck configurations	For consideration		State and local highway and highway safety agencies; NHTSA
S.3 Comparative evaluations of safety performance of truck configurations using the case-control method	Core track project		State and local highway, highway safety, enforcement agencies
S.4 Comparative evaluation of safety performance of truck configurations using trucking company data	For consideration		State and local highway, enforcement agencies; truck operators
S.5 Evaluation of safety performance of truck configurations with computer simulation modeling and track testing	Core track project	Identify safety improvement opportunities within present limits	
S.6 Model to project frequency of crashes on a road as a function of vehicle mix and traffic volume on the road	May be deferred	Evaluation of safety policies concerning enforcement, traffic management, and road design	
Enforcement Research			
E.1 Relationship between enforcement effort and compliance with size and weight laws	Core track project	Valuable for planning and budgeting enforcement programs	State and local highway, highway safety, enforcement agencies
E.2 Detailed accounting of truck size and weight enforcement costs	For consideration	Provide a benchmark for costs and expenditures	Enforcement agencies
E.3 Survey of truck size and weight enforcement and regulation in other countries	May be deferred	Identify immediately applicable improvements	Road authorities of other countries
E.4 Pilot studies to evaluate alternative enforcement methods, including information technology applications and automated enforcement	May be deferred	Identify immediately applicable improvements	State and local highway and enforcement agencies; technology developers
Mode and Vehicle Choice and Freight Market Research			
M.1 Adaptation and testing of freight mode choice models for application in truck size and weight limit policy studies	Core track project		
M.2 Mode and vehicle choice model for application in truck size and weight limit policy studies	Core track project	Model would be useful for evaluating user fee changes and other policies to mitigate truck costs	May require shipper or truck operator survey; Census Bureau
M.3 Method of projecting railroad industry revenue impact of changes in size and weight limits, including short line impacts	For consideration		Railroad companies, FRA, Surface Transportation Board

Cross-Cutting Topics; Evaluation of Regulatory Options			
C.1 Truck traffic, weight, and configuration databases necessary for truck size and weight research and evaluations	Core track project	Would have general value for freight planning and asset management	State and local highway agencies, FHWA Long Term Infrastructure Programs
C.2 Methods for incorporating common features of regulatory schemes in evaluations of costs and benefits of changing truck size and weight limits	May be deferred		
C.3 Analysis framework for evaluating the potential of the coordination of size and weight regulations with other road management policies	May be deferred	Coordination would have benefits under present size and weight limits	
C.4 Protocols for staged pilot evaluations of truck configurations	Core track project		State and local highway agencies, highway safety agencies, enforcement agencies, truck operators

Table 2.2 Core Research Tracks

Project	Description	Importance for Evaluating Limits	Shortcomings of Existing Methods	Feasibility	Duration; Cost
Freight Market and Traffic					
Truck traffic, weight, and configuration database from WIM and other sources	Estimate traffic volumes and weight spectra for U.S. road system; provide weight data for impact modeling	Necessary for estimates of all impacts of changes in limits and for developing bridge and pavement models	Standard database of traffic volumes and weight spectra does not exist	FHWA Vehicle Travel Information System, USDOT Comprehensive Truck Size and Weight Limits Study provide starting point	14–22 months $600,000–$850,000 Early completion would facilitate infrastructure, enforcement research.
Discrete-continuous choice model of freight mode and vehicle configuration choice	Develop model for projecting effect of changes in truck costs on freight mode share and configuration choice	Impacts of a change in limits are driven by the effect on truck freight traffic & configurations used	Method of USDOT 2016 study depends on arbitrary assumptions; deterministic models overstate mode shift	Current National Cooperative Freight Research Program project developing mode choice model; vehicle choice model may require new data collection	24–30 months $900,000–$1,100,000
Infrastructure					
Pavement analysis methods for heavier axle limits and active suspension systems	Develop method to simulate impact of higher maximum axle weights and diverse axle configurations	USDOT requires the capability to evaluate changes in axle weight limits and diverse multi-axle groups	Present models are unreliable for heavy axles, multiaxle groups, & overlay pavements	Recent research on costs of heavy permit vehicles suggests directions for model development	30–36 months $850,000–$1,000,000
Comprehensive model of the relationship of bridge deterioration and service life to vehicle loads	Estimate relationship of loads to deterioration and loss of service life using bridge condition and traffic data	Costs related to structural inadequacy are potentially a major cost of some limit changes	Past methods are not capable of projecting physical effects on bridge condition of changes in limits	Simple model could be developed with available load and bridge condition data	28–36 months $750,000–$1,200,000
Safety					
Evaluations of relative crash risks of alternative truck types by the case-control method	Develop and demon-strate procedures for measuring relative crash risks of alternative truck types using the case-control study design	An estimate of the relative crash risk of alternative truck types is necessary for projecting safety impact of limit changes	Data limitations have hindered attempts at direct measurement of crash rates of alternative vehicles	Truck crash studies by Insurance Institute for Highway Safety show feasibility	30–48 months $400,000–$750,000
Protocols for evaluating truck	Develop protocols for use of simulation	Would provide means to compare vehicles' per-	Changes in limits may lead to use of new	Experience in past U.S. studies, use in other	30–36 months $350,000–$450,000

performance with simulation, track testing, and field trials	modeling, track testing, and trials in evaluations of limits	formance characteristics linked to crash risk; can guide performance-based regulation	vehicles for which safety cannot be evaluated with historical data	countries indicate practicality	
Enforcement					
Relationships between enforcement level of effort and frequency of violations of size and weight regulations	Determine relationships between overload frequency and characteristics of weight enforcement programs: level of effort, methods, legal provisions	Applicable for assessing impact of a change in limits on enforcement, coordinating regulations with enforcement, improving enforcement cost-effectiveness	The combined effect of size & weight limits and enforcement in determining actual axle weights has not been analyzed in past truck size and weight studies	Would depend on truck weight database from a prior roadmap project; would require data collection on enforcement effort and practices	18–24 months $500,000–$750,000 (assuming weight data are available from a prior project)

3

CONCLUSIONS

The following conclusions about research needs and priorities are derived in part from the committee's examination of the experience of the USDOT 2016 truck size and weight limits study (FHWA 2015a, 2016a) and the 2015 TRB committee review of the technical analysis of the USDOT study (TRB 2015). This recent experience reinforces certain conclusions of the 2002 TRB committee study *Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles* (TRB 2002), which are cited in the following section. Conclusions are presented on eight topics:

- The value of research on truck size and weight regulations.
- Limitations of impact projections.
- The value of broadly applicable research.
- The importance of general purpose data programs.
- The need to match research to policy objectives.
- The value of tests and trials in evaluations of truck size and weight limits.
- Emerging technologies and truck size and weight regulations.
- Organizational needs and options.

Value of Research on Truck Size and Weight Regulations

A program of research and data collection targeting the most important gaps in understanding of impacts, together with improvements to existing data systems, would strengthen the federal and state governments' capabilities to project the consequences of proposed changes in truck size and weight limits. Research could reveal important opportunities to improve safety and productivity and to control highway construction and maintenance costs through better regulatory and management decisions.

Limitations of Impact Projections

Projections necessarily will be only approximate indicators of the range of possible outcomes of changes in the regulations. The 2002 TRB committee observed that “models and data will never be adequate for providing more than plausible indications of how institutions, markets, and technology will react to regulatory changes, especially in the long run.… Responsible regulation is a process: the regulatory authority should do the best prior analysis possible, but once regulations have been changed, the consequences must be systematically observed and adjustments made where necessary” (TRB 2002, 3–4).

A truck size and weight study should communicate this uncertainty to users of the study and identify uncertainties that are critical for decisions. The TRB committee that reviewed the USDOT 2016 study summarized techniques used in past studies for quantifying uncertainties, including sensitivity analysis to show how impact estimates are affected by statistical uncertainties in models and by study assumptions (TRB 2015, 14–15).

Notwithstanding this uncertainty, legislators and government executives are regularly confronted with decisions on truck size and weight regulations and require technical guidance based on the best available information. Past studies, while acknowledging the uncertainties, concluded that the evidence was sufficient to support recommendations. The 1964 federal study recommended specific changes in federal limits together with the introduction of vehicle performance standards (DOC 1964, 2–6). The 1981 federal study by USDOT did not provide recommendations but reached firm conclusions about impacts of alternative limits that were a source of guidance for changes enacted in 1983. Earlier TRB committees (TRB 1990a, 1990b, 2002), consistent with their charges, recommended changes in limits, coupled with monitoring, enforcement, and user fee provisions.

Value of Broadly Applicable Research

The data and analysis capabilities needed to project impacts of changes in limits are largely the same as the ones needed to manage the highway freight system under present limits—for bridge, pavement, and safety management; capacity planning; and setting of user fees. The projects in the roadmap that have the greatest potential value are projects that would improve truck size and weight limit evaluations and also produce results with broader applications for highway management.

For example, research on the determinants of bridge deck performance would have value for bridge life-cycle cost analysis, design, and asset management. Expanding the network of WIM sites would be valuable for asset management and capacity planning. In general, understanding the relationship of truck traffic characteristics to highway agency costs and user costs is necessary for highway system management regardless of whether size and weight limits are changed.

The potential for broad application will be important in justifying investment in the roadmap research and in recruiting support from the various federal and state government agencies from which cooperation will be required to conduct the research. Research should be planned and designed with consideration of the full range of applications that would have the greatest long-term value.

Importance of General Purpose Data Programs

Ongoing data programs maintained by the state highway agencies for management purposes and by the federal government for performance monitoring and research are the basis of understanding of truck impacts and have been among the principal resources in past evaluations of proposed changes in limits. These include state highway agencies' bridge and pavement management systems and traffic, crash, and vehicle weight databases; USDOT's motor vehicle crash and motor carrier enforcement data systems, Long-Term Infrastructure Performance Programs, and National Bridge Inventory; the Surface Transportation Board's Carload Waybill Sample; and the Census Bureau's Commodity Flow Survey and Vehicle Inventory and Use Survey. Strengthening these information systems would allow improved highway management today as well as improved understanding of the costs and benefits of changes in truck size and weight limits.

Evaluation of truck size and weight regulations requires data on pavement and bridge condition, safety, and truck weights and truck traffic volume on roads owned and maintained by county, city, and other local governments. Programs to collect infrastructure and traffic data on local roads are generally weak. Local roads carry about 15 percent of U.S. combination truck-miles of travel, but include nearly 80 percent of U.S. road mileage (FHWA 2017a, Tables HM-16, VM-1). Bridges and pavements on local roads typically are of lighter construction than those on major roads, and local governments often have fewer resources for maintenance and enforcement than state governments. Therefore, many local roads are more susceptible than major roads to effects of changes in truck sizes and weights.

Need to Match Research to Policy Objectives

The TRB 2002 and 2015 committees recommended that the objective of evaluations of truck size and weight limits should be to identify policies that would increase public benefits through improved operation of the highway freight transportation system:

> The best way to control the costs of accommodating existing and future truck traffic is by coordinating practices in all areas of highway management: design and maintenance of pavement and bridges; highway user regulations; and highway user fees…. Whenever Congress contemplates changing policy in any one of these three areas in the federal aid highway program, it should at the same time consider the need for complementary changes in the other two. (TRB 2002, 3)

> The goal of research should be development of comprehensive strategies for improving the performance of highway freight transportation. Size and weight limits alone provide only weak leverage for improving performance. Future truck size and weight studies should be organized as evaluations of comprehensive policy options rather than evaluations of alternative truck configurations. (TRB 2015, 4)

The state, local, and federal governments are together responsible for all aspects of the operation of the highway system, including design, asset management, safety regulation, size and weight regulations, user fees, and enforcement. The impact of a change in size and weight limits depends on practices in each of these areas. As the description in Chapter 1 of the structure of truck size and weight studies noted, research will be required to develop methods that can be used in future studies to evaluate coordinated policies, including the effects of user fees, enforcement, asset management, and vehicle performance standards on truck traffic costs.

A USDOT study conducted at the direction of Congress must fulfill the specific requirements of Congress, which may include narrowly defined regulatory questions such as the impact of exempting particular routes in one state from a federal limit. However, a federal truck size and weight study intended to be comprehensive, that is, to provide general policy guidance, will be most useful if it is organized as an evaluation of coordinated policies that seeks to identify opportunities for increasing public benefits.

Value of Tests and Trials in Evaluations of Truck Size and Weight Limits

Road trials and vehicle testing would be useful components of evaluations of proposed changes in limits. The new vehicles that come into use after a nationwide change in regulations are likely to differ from any dimensionally similar vehicles in use before the change with respect to loads, routes, equipment characteristics, and operator characteristics. For example, since federal law legalized use of twin 28-ft trailers in 1983, the predominant users of this configuration have been nationwide parcel and less-than-truckload carriers, but most prior use had been intrastate carriage of agricultural products (TRB 1986, 75–80). Therefore, the pre-1983 experience had limited value for predicting the performance of post-1983 twin trailers. The 1983 changes in federal regulations also led to nationwide use of the 53-ft single-trailer combination, with which there had been practically no previous experience.

The TRB committee that authored the report *Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles* recommended a program of road trials (termed pilot studies in the report), involving selected carriers and a limited network of roads, as a means to evaluate changes in truck size and weight regulations to supplement the information available from historical experience (TRB 2002, 200–203). Trials on a range of scales have been conducted in the United States and other countries, from test track experiments to measure the dynamic properties of vehicles to the use of new vehicles in commercial freight operations that are subject to systematic monitoring. Track testing and simulation modeling can guide the specification of standards to assure acceptable performance of new vehicles with respect to stability, control, and pavement impact. Systematically conducted road trials have been used to provide a realistic check on motor carrier use of new vehicles and infrastructure interactions. A road trial would provide information on crash characteristics for new vehicle types, although differences in crash rates among vehicle types would be observable only in large-scale trials of long duration.

A trial would be undertaken with safeguards. Vehicles would be evaluated for stability before the trial with track testing and engineering analysis. Drivers and participating carriers would be required to meet standards for past safe operation. Roads designated for the trial would be compatible with the characteristics of the trucks. The trials would be subject to monitoring to detect incipient problems. Such trials would be an improvement in safe practice in comparison with present practice, under which changes in limits and the issuance of permits for oversize and overweight vehicles usually occur without systematic monitoring of consequences.

Emerging Technologies and Truck Size and Weight Regulations

Technological developments in the motor vehicle and trucking industries will influence the consequences of changes in size and weight limits. The following are some of the technologies in truck transportation and trucking regulation that may become more important over the next 10 to 15 years and the truck costs that they will affect:

- Platooning: truck freight cost, safety, and pavement and bridge costs.
- Advanced driver assistance systems, including electronic stability control and collision avoidance: crash risk (in particular, for multitrailer combinations).
- Automated driving systems: truck freight cost, crash risk, and pavement and bridge costs.
- Active suspensions: pavement and bridge costs (by controlling dynamic loading).

- Truck telematics, including vehicle tracking, electronic logging, safety analytics, and onboard mass monitoring: enforcement cost and effectiveness and truck freight cost.
- Electrification: truck freight cost and pollution cost.

Some consequences of these technologies are clearly relevant to government decisions about truck size and weight regulation. For example, stability control and other forms of automation might reduce any differences in crash risk related to vehicle configuration. Technological advances that substantially reduce truck freight costs will affect modal competition and the volume of truck freight.

The research problem statements include research tasks to examine the influence of some of these technologies, including use of information technologies in enforcement (problem statements E.3 and E.4) and the effect of platooning on pavement and bridge costs (problem statements P.3 and B.7). Research to develop procedures to evaluate the performance of vehicles with track testing (problem statement S.5) will provide information on the potential value of electronic stability control, active suspensions, and collision avoidance systems for mitigating the costs of truck traffic. For technologies still in an early stage of development (for example, electrification and full automation of large trucks), it will be necessary to monitor progress until the course of the technology is clearer and specific research needs become evident.

Organizational Needs and Options

USDOT should consider the research topics proposed in this report as components of its coordinated research plan to meet the needs of its policy, freight, infrastructure, and safety programs. If USDOT determines that improved projections of particular categories of impacts are necessary, then the roadmap projects that address these impacts can guide the research.

The committee was not charged with recommending the internal organization of USDOT research, but presumably most federal research projects in the roadmap would involve collaboration among FHWA offices (including the freight, research, infrastructure, policy, and safety offices) or with other USDOT agencies (National Highway Traffic Safety Administration [NHTSA], Federal Railroad Administration [FRA], or the Federal Motor Carrier Safety Administration). FHWA could submit projects that would have products useful to the states for consideration by NCHRP. Projects could also be organized through FHWA's Transportation Pooled Fund Program as joint projects of FHWA, other federal agencies, states, and other interested parties. Certain safety projects could involve industry participation and in-kind contributions.

To provide an organizational home for research in the roadmap, USDOT may wish to designate an office responsible for coordinating the program of all research projects that are expected to contribute to improving capabilities for evaluating changes in truck size and weight limits. The coordinator would be responsible for maintaining communication among all the parties contributing to the research program, including sponsors, highway agencies, and investigators for the various research projects; identifying specific coordination needs (for example, data and modeling capability requirements); and setting milestones and tracking progress toward the program's objectives.

REFERENCES

Abbreviations:

AASHTO	American Association of State Highway and Transportation Officials
ATRI	American Transportation Research Institute
DOC	U.S. Department of Commerce
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GAO	U.S. Government Accountability Office
NTC	National Transport Commission (Australia)
NYSDOT	New York State Department of Transportation
RTAC	Roads and Transportation Association of Canada
TRB	Transportation Research Board
USDOT	U.S. Department of Transportation

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APPENDIX A

RESEARCH PROBLEM STATEMENTS

PAVEMENT RESEARCH

The main traffic input to any pavement design and analysis is truck loading. Pavement wear increases exponentially with respect to axle weight. Therefore, the wear caused by trucks with the heaviest axle loads, even if these trucks constitute only a small fraction of traffic, will affect pavement service life, thus affecting pavement rehabilitation and maintenance strategies and costs.

In general, past studies' estimates of the effect of changing truck size and weight limits on pavement costs (highway agency costs for rehabilitation and user costs) have been small compared with other categories of costs and benefits. For example, the U.S. Department of Transportation (USDOT) 2016 study estimated changes in pavement costs ranging from a 4 percent decrease to a 3 percent increase among its size and weight scenarios, with the largest cost increases predicted in a scenario in which the tandem axle weight limit is increased and a scenario in which some freight is projected to be shifted from being carried on tandem axles to being carried on single axles, with no changes in weight limits (Federal Highway Administration [FHWA] 2015b, 57–59). Pavement cost estimates were small because most limit changes evaluated did not involve changes in axle weight limits and because projected changes in truck traffic volume were moderate. The linear elastic method and empirical transfer functions were used for the calculations.

Simple methods of estimating pavement impacts are adequate when the magnitude of the effects is known to be small. However, USDOT should have the capability to evaluate a wide range of changes in weights and dimensions, in particular, higher axle load limits, variations in axle groupings and axle spacing, and alternative tire types and sizes. Existing pavement models may not be reliable in predicting pavement response to axle loads, axle groupings, and axle spacing that differ greatly from those in common use. USDOT also should have evaluation methods applicable to all roads. The pavement impact evaluation method of the 2016 USDOT study was not applicable to roads with overlay pavement or to the local road network.

The research needed to strengthen USDOT's capability to project impacts on pavements of changes in truck size and weight limits could produce valuable results regardless of whether limits are changed. Research could reveal opportunities to reduce pavement wear through modifications to tire characteristics, axle spacing, and dynamic loading as controlled by vehicle suspension features.

A research program made up of the following projects would provide methods for USDOT to evaluate pavement effects on all U.S. roads of the full range of size and weight regulatory alternatives:

P.1 Realistic assessment of impact of a change in truck weight and size limits on the condition of pavements of the road network.

P.2 Method of estimating the effects of a change in truck size and weight limits on highway agency pavement costs and highway user costs.

P.3 Effect of truck platooning on pavement performance and costs, and methods to control the effect.

The following analysis of the shortcomings of present methods provides background to the research problem statements.

Directions for Improvement to Pavement Models for Truck Size and Weight Limit Evaluations

The models used in past truck size and weight limit studies have not satisfactorily considered two truck features that affect pavement interaction:

- Axle configuration: The effects of axle spacing and configuration on pavement damage is not as straightforward and well established as that of axle load and repetition. Chatti et al. (2004) stated that trucks with more axles and axle groups cause less fatigue damage as compared with those with single axles. Although Salama et al. (2006) reached the same conclusion for fatigue damage, their study found that heavier trucks with multiple axles cause more rutting that those with single and tandem axles. However, the study could not produce any firm conclusion on the effect of axle configuration on pavement roughness. The effects of an increasing number of axles and axle spacing on pavement behavior are complex and may not be addressed by the current linear elastic theory, especially for asphalt concrete pavement. The impact of speed, longitudinal spacing, and temperature, among others, play important roles.

- Tire contact stresses and area: Tire loading is conventionally simulated as vertical pressure that is assumed to be distributed on a circular area. However, many studies in the literature showed that tires apply nonuniform three-dimensional contact stresses, which are not equal to tire pressure (Al-Qadi et al. 2002). The characteristic of the contact stress distribution is expected to change under higher axle loads or tire pressure, which may accelerate the formation of rutting and near-surface cracking on the pavement surface. Therefore, research is needed to incorporate accurate tire-pavement interaction into the assessment of trucks with higher axle loads on pavement deterioration.

The 2016 USDOT Truck Size and Weight Study (FHWA 2015c) followed a scenario-based approach in which six hypothetical scenarios were developed by simulating six trucks (that is, scenarios) that exceed present federal limits on weight, length, or numbers of trailers. For each hypothetical scenario, collected traffic data were modified for computing new sets of traffic inputs (for example, axle load spectra, daily truck traffic) to reflect changes resulting from allowing the scenario trucks to travel on the freight network. Later, selected pavement sections were simulated using the American Association of State Highway and Transportation Officials (AASHTO) AASHTOWare Pavement ME (Mechanistic-Empirical) Design® software under hypothetical (using modified traffic data) and realistic (using true collected traffic data) scenarios. For each scenario, a service life is computed, which is defined as the year in which any of the selected performance criteria (rutting, bottom-up cracking, and international roughness index) exceeds preset limits. Finally, the difference between the service lives are quantified economically using life-cycle cost analysis. A similar scenario-based approach was followed by Ghosn et al. (2015). In this study, two scenarios, with heavier trucks (actual traffic) and without heavier trucks (hypothetical), were simulated on selected pavement sections, resulting in different service lives. Later, life-cycle cost analysis linked the differences between the service lives to economic cost.

Another common approach for quantifying the pavement damage caused by truck traffic is "marginal pavement damage cost (MPDC)," which is the assessment of the "pavement consumption" by trucks. Two main methods are used to compute MPDC. The first method is based on normalizing total life-cycle cost with respect to equivalent single axle loads (ESALs). The service life of pavement is calculated under actual traffic conditions and then the service life is used as a trigger for rehabilitation activities (for example, overlay) within the life-cycle cost analysis. Although Al-Qadi et al. (2017) compute the pavement service life using regression models developed based on field data, Prozzi et al. (2012) use the AASHTOWare Pavement ME Design® software. The second method builds on developing surrogate models that input a few design variables and output total life-cycle cost. For example, Ahmed et al. (2013) used freezing index and ESALs as input variables in the developed surrogate model to predict total life-cycle cost. The derivative of the surrogate model was taken with respect to ESALs, which produced the MPDC. In summary, the MPDC approach essentially computes the cost spent on pavement throughout its life and normalizes it per ESALs, which is later used to assess additional ESALs applied by trucks operating at higher weights with respect to legal trucks.

Each approach used to compute pavement damage cost has its own limitations. The limitations of existing approaches and research efforts are grouped into three categories: limitations of MPDC approach (i), limitations of scenario-based approach (ii), and overall limitations that are shared by these two approaches (iii).

The primary limitation of the MPDC approach is that it uses a single parameter to incorporate truck traffic load into damage computation. This parameter has traditionally been selected as ESALs. This parameter does not capture the aforementioned highly nonlinear impact of heavier axle loads and tire contact stresses on pavement behavior. It was developed based on statistical analysis of data collected six decades ago. In addition, the development of ESALs is very sensitive and subject to the performance criteria selected as a reference (for example, bottom-up cracking under single 18-kips axle) and to the methodology used to compute such criteria (for example, linear elastic theory or finite element analysis). Although the MPDC approach could be appropriate to compute penalty fees for trucks that violate existing weight limits (that is, a permit fee), its use becomes questionable when applied to capturing the accurate impact of possible modifications to existing limits.

An alternative approach could be using a scenario-based approach as previously explained. The main limitations of such an approach could be attributed to the state-of-the-practice pavement design methodology (that is, the AASHTOWare Pavement ME Design® software), as it cannot capture the nonlinearities in loading conditions (for example, three-dimensional nonuniform contact stresses, realistic tire footprints) and material properties (for example, anisotropic stress-dependent behavior for granular materials, viscoelastic behavior of asphalt concrete, proper erosion estimation of base layer for concrete pavement). Moreover, as mentioned in the TRB committee review of the USDOT 2016 study, predicted service lives from the design software sometimes exceed 50 years, which falls out of the typical service life range of 20 to 30 years. Although a field validation and calibration of the software is being conducted, accurate assessments still will be a challenge because the issue at hand is outside the scope of the currently used approach.

Finally, there are general limitations shared by both approaches. The first is the incorporation of inherent uncertainties in pavement design and analysis. As stated in the TRB committee review of the USDOT Comprehensive Truck Size and Weight Limits Study: “The cost estimates are subject to uncertainty from two sources: uncertainties in the input data on pavement structure and truck traffic and uncertainties from the limitations of the modeling method used (in particular, the exclusion of some pavement types and distress mechanisms in the estimates).” (TRB 2015, 35) The second general limitation the difficulty of obtaining regional life-cycle cost analysis data to account for variations in rehabilitation and maintenance schedules across the states. The third is the lack of data on traffic and maintenance activities on local roads. Finally, the pavement response accuracy to moving a load through nonuniform three-dimensional contact stresses is yet another limitation in current modeling.

PAVEMENT RESEARCH PROBLEM STATEMENT P.1

Realistic assessment of impact of modifying truck weight and size limits on pavement network.

Problem Statement

To reduce the uncertainties in estimates of pavement costs of changes in size and weight limits in the 2016 USDOT truck size and weight study and earlier studies, methods are needed that are applicable to the entire network of local roads and state highways that would be exposed to the traffic of new vehicles (including local roads and roads with overlay pavements), can predict the impacts of vehicles that differ greatly from common existing vehicles, and can estimate the costs of projected physical impacts. This problem statement outlines research to develop the method of projecting physical pavement impacts. Problem statement P.2 to follow outlines research to estimate the costs of the physical impacts.

Research Objectives

The objective of this research is to use or develop a pavement analysis framework that realistically simulates the impact of truck traffic on the pavements of U.S. roads. This framework should be capable of projecting the impacts of truck axle weights, gross weights, and axle spacing that differ from current federal limits. The research will also include a demonstration of the use of the framework to assess the systemwide impact of possible modifications to existing limits.

Possible Approaches

Task 1. Evaluate the capability of existing pavement design and analysis methods for realistic simulation of the effects of trucks on pavement structures. During the evaluation, special attention should be given to the following issues:

- Realistic tire contact stresses and areas.
- Impact of axle and tire spacing on pavement performance.
- Simulation of large axle configurations.
- Applicability of analysis methods to overlay pavements.
- Incorporation of the effects of dynamic loading.
- Capturing the impact on local and low-volume roads.

Task 2. If existing methods do not address the aforementioned issues, two options may be considered:

- Develop a pavement design and analysis framework, using existing methods, capable of the evaluation previously outlined.
- Propose a plan to develop a new pavement design and analysis method or to modify existing methods.

Data Requirements

The required data include:

- Material properties of selected pavement sections.
- Loading characteristics.
- List of rehabilitation and maintenance activities and their corresponding costs from each state.
- Pavement performance data and performance model (if it exists) from each state.
- Weigh-in-Motion (WIM) data from each state.

Present Status of Research

The following studies developed pavement models that have some of the required capabilities: Gamez et al. (2018), Darab et al. (2011), Wang and Al-Qadi (2009), Selesneva et al. (2004), Darter et al. (2001).

Estimated Cost and Research Period

30 to 36 months
$850,000 to $1,000,000

Priority

This model development is necessary to identify opportunities to control pavement wear and costs through truck size and weight limits and through modifications to axle configurations, tires, and suspensions. The potential savings may be substantial; therefore, the research merits high priority.

PAVEMENT RESEARCH PROBLEM STATEMENT P.2

Method of estimating the effects of a change in truck size and weight limits on highway agency pavement costs and highway user costs

Problem Statement

Pavement cost estimates in past truck size and weight studies have depended on assumptions about highway agency responses to changes in the rate of pavement wear on the highway system that are unverified. Models of construction and maintenance costs similarly are of uncertain validity. The pavement cost analysis method in most past truck size and weight studies did not require a user cost model. Models and methods for projecting highway agency responses, construction and maintenance costs, and user costs require evaluation and development.

Research Objectives

Develop a method of estimating the effect of changes in truck size and weight limits on highway agency costs for constructing and maintaining pavements and on highway user costs as affected by pavement condition and pavement construction.

Possible Approaches

The research could proceed according to the following tasks, using the outcome of the research described in problem statement P.1:

1. Define scenarios in terms of change in truck traffic volume and in the distribution of axle configurations and weights on a road network.
2. Define alternative assumptions about highway agency response to a change in the rate of pavement wear caused by changes in loadings:
   a. The agency maintains user costs (average road roughness) and resurfacing schedule.
   b. The agency maintains existing level of pavement expenditures.
3. Compute pavement design, resurfacing interval, and average pavement condition over multiple resurfacing cycles for each agency response assumption.
4. Compute highway agency and user costs and environmental costs for each response.
5. Conduct a simulated trial evaluation of a change in size and weight limits, for example, assuming the change in truck traffic volume and axle weight spectra projected in one of the scenarios in the USDOT 2016 truck size and weight study.

Data Requirements

As noted in the previously stated possible approach.

Present Status of Research

The following studies developed a framework to estimate pavement cost due to truck loading: Al-Qadi et al. (2017), Ghosn et al. (2015), Nassif et al. (2015), (Ahmed et al. 2013), Prozzi et al. (2012)

Estimated Cost and Research Period

18 to 28 months
$300,000 to $450,000

Priority

This research would be important as a trial to demonstrate the usefulness of the physical model of pavement impact developed in the research outlined in problem statement P.1. The improved physical model of P.1 is the critical pavement evaluation need.

PAVEMENT RESEARCH PROBLEM STATEMENT P.3

Effect of truck platooning on pavement performance and costs, and methods to control the effect

Problem Statement

With the widespread implementation of intelligent technologies used in autonomous and connected trucks to enable the connection among vehicles and between vehicles and infrastructure, truck platooning will be more efficient and feasible. Truck platooning can be defined as a convoy of trucks traveling with very close spacing between trucks. Use of the method is expected to bring many advantages, including reducing congestion and braking and accelerating and improving safety, traffic flow, and fuel efficiency. The impact of truck platooning on the pavement structure has not been studied.

Research Objective

The objective of the study is to quantify the impact of truck platooning on pavement structures with present and alternative truck weight and size limits.

Possible Approaches

1. Review the transportation network to assess the potential implementation of truck platooning (that is, computation of highway miles where platooning could be used).
2. Conduct a comprehensive literature review to understand if the existing pavement design guidelines can accurately simulate the truck platooning. If not, develop a framework that can capture the truck platooning effects (for example, more channelized traffic and more frequent loading) on pavement behavior.
3. Quantify the impact of truck platooning on pavement performance through life-cycle cost assessment and life-cycle analysis.
4. Develop a framework that explains how truck platooning can affect freight transportation and hence, weight and size limits, and recommend the proper approach to control any negative impacts.

Data Requirements

Data on actual dimensions and performance characteristics of truck platoons, and on routes open to or suitable for platoons, as this technology comes into use.

Present Status of Research

No research has been conducted on the impact of truck platooning on pavement. Noorvand et. al (2017) made a preliminary analysis of controlling the lateral positions of the trucks in a platoon to reduce the pavement damage.

The European Union in 2018 began a large-scale 3-year trial of truck platooning, the ENSEMBLE Initiative, which is to include assessment of the impact of platooning on pavement, bridges, tunnels, and traffic flow, as well as other environmental and economic effects (Hoedemaeker 2018).

Estimated Cost and Research Period

$200,000 to $350,000
18 to 24 months

Priority

Methods for projecting the pavement impacts of platooning will become necessary as the practice begins to be implemented. Research may reveal opportunities for mitigating pavement costs (for example, through adjustments to spacing or tracking in platoons).

BRIDGE RESEARCH

A change in truck size and weight limits is likely to affect the cost and urgency of bridge maintenance and construction. An increase in the size and legal weight of trucks may cause highway agencies to post more bridges (that is, to impose weight limits for vehicles using certain bridges that are lower than the normal legal maximum weights), detour heavier trucks, and commence a program of bridge strengthening and replacement, especially for short-span bridges. The actions taken would depend on funds available and budget priorities.

The effects of increases in truck size and weight limits on bridges may include lost useful life because of increased load-induced deterioration of the structure, shortened deck life, and risk of damage. The magnitudes of these impacts will depend on the effect of the change in limits on the distribution of truck axle weights and on the frequency of truck crossings of bridges. The costs of bridge impacts include the costs of bridge replacements or reconstruction that highway agencies undertake and the change in user costs due to bridge postings, lane closures for bridge maintenance, and detours for bridge replacements.

Bridge-related costs have been the largest projected cost in several past prospective evaluations of the impact of allowing larger trucks on roadways (for example, in the TRB committee study *Truck Weight Limits* [TRB 1990a, 212], the TRB committee study of the Turner proposal [TRB 1990b, 180–181], and USDOT's 1981 [USDOT 1981, V-6] and 2000 [USDOT 2000a, 38] truck size and weight limits studies). The possibility of higher costs for bridge construction and repair would be a major concern of state highway agencies if size and weight limits were increased.

In spite of the evident importance of bridge impacts, poor understanding of these costs is a major obstacle to evaluating truck size and weight limits. The 2002 TRB committee report *Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles* reviewed the major past studies of size and weight limits and concluded that (TRB 2002, 3):

> The methods used in past studies have not produced satisfactory estimates of the effect of changes in truck weights on bridge costs. Past studies have not evaluated the changes in

> the risk of bridge failure or in useful life that would be caused by changes in truck weights. Instead, they have estimated the cost of maintaining the existing relationship of legal loads to bridge design capacity through bridge replacement. The estimated cost of these bridge replacements is the biggest component of the projected costs of accommodating larger trucks; however, many of the projected replacements would, if actually carried out, buy very little risk reduction. Past studies have not included quantitative evaluation of alternative methods of attaining the same or greater risk reduction through much less costly bridge management strategies.

The TRB committee proposed an alternative to the conventional method of estimating bridge costs that the committee believed would be more useful for guiding decisions on truck size and weight limits (TRB 2002, 60–80).

The inadequacy of past bridge cost estimates cause the great variability of the estimates from study to study and the instability of the estimates with respect to small changes in assumptions. For example, the USDOT 2000 study estimated highway agency construction costs for replacing deficient bridges at $51 billion and user costs from delays caused by bridge construction at $203 billion (in 2000 dollars) in a regulatory scenario in which 124,000-lb double trailer combinations, 90,000-lb tractor semitrailers, and 64,000-lb single-unit trucks all were allowed to operate on a restricted network of Interstates and other major roads (USDOT 2000b, VI-12). The 2016 USDOT study estimated highway agency bridge replacement costs of $1.1 billion if 91,000-lb tractor semitrailers were allowed to operate and $5.4 billion (in 2011 dollars) if 129,000-lb triple trailers were allowed to operate on a similar network of Interstates and major roads (FHWA 2016a, 10–11). That is, the 2000 highway agency bridge construction cost estimate is on the order of 10 times the estimate in the 2016 study for regulatory scenarios involving similar vehicles and road networks. The details of the scenarios differ in the two studies, but not enough to explain a cost difference of this magnitude. The 2016 study's investigators were unable to account for the difference (FHWA 2016b, 27):

> The desk scan reveals differences in analysis approach or methodology, etc. that render direct comparisons of structural impacts between the current study and previous ones untenable…. [D]ifferences in analysis method, determination of control or base vehicles, governing threshold criteria, study limits (networks), presentation of results, etc. prevent direct comparison.

A 2017 study conducted for AASHTO estimated bridge-related costs of allowing the same larger combination vehicles that were evaluated in the 2016 USDOT study, but used a different method of determining the structural adequacy of bridges and different unit costs of bridge replacement and included costs for all bridges rather than just bridges on major highways as in the USDOT study. The estimates were $10 billion to $54 billion (the range solely reflected uncertainty in unit costs) for 91,000-lb tractor semitrailers and $29 billion to $83 billion for 129,000-lb triple trailers (compared with $1.1 billion and $5.4 billion for the two vehicle types respectively in the USDOT study) (Wassef 2017). A large share of the difference between the 2017 and 2016 studies' cost estimates presumably is due to the difference in the road networks considered, but differences in unit costs and in methods of rating bridge capacity would also contribute to differences in the cost estimates. The AASHTO study report notes the difference with the USDOT 2016 bridge cost estimates, but does not offer a quantitative accounting of the difference.

Cost estimates that vary over such a great range have little value for guiding regulatory decisions. Some of the past studies have defended the relevance of the estimates by interpreting them as upper bounds on bridge costs, but as the TRB committee that reviewed the USDOT 2016 study pointed out (TRB 2015, 25), this characterization is incorrect. If highway agencies choose not to undertake all the bridge replacements that the studies predict, the resulting costs from lost useful life and increased risk of accumulated damage are unknown and possibly greater than the bridge replacement cost estimates.

The major component of the bridge costs estimated in these past studies was the cost of replacing bridges that were structurally adequate to carry current legal loads but inadequate for the trucks allowed after the hypothesized change in size and weight limits. The studies do not attempt to predict the physical consequences of exposure of bridges to truck traffic. Instead, it is assumed that the highway agency acts to prevent most physical harm to bridges through maintenance, strengthening, or replacement of vulnerable bridges.

The sensitivity of bridge cost estimates derived by this method to changes in assumptions was pointed out in a 1994 U.S. General Accounting Office (GAO) report on truck size and weight regulations. FHWA, at GAO's request, estimated bridge replacement costs on Interstate highways if 129,000-lb double trailer and 115,000-lb triple trailer combinations were allowed to operate nationwide, assuming two alternative criteria for determining whether a bridge would require replacement: replacement if the new loads would exceed 55 percent of the yield stress in any bridge member and replacement if the new loads would exceed 65 percent of yield stress. Estimated replacement costs were $1.3 billion for the 65 percent criterion and $18.3 billion, 14 times greater, for the 55 percent criterion (GAO 1994, 24–25). GAO again pointed out in a 2000 report that FHWA's method of estimating bridge costs is flawed because the benefits of replacing bridges according to a conservative standard of structural adequacy rather than a more liberal one are unknown (GAO 2000, 6, 21).

The GAO 1994 report concluded that it would be reasonable to apply a more liberal criterion (the operating rating, which allows loads up to 75 percent of yield stress) in estimating the bridge-related costs of changes in size and width limits, because most states used this criterion at the time in determining which bridges require posting of weight restrictions. State highway agencies vary in the criteria they apply to determine weight limits for load-posted bridges. Of 43 states that responded to a 2014 survey, 5 reported using the most conservative criterion, the inventory rating (55 percent of yield stress); 22 used the operating rating; and 16 used an intermediate rating or another method of rating (Hearn 2014, 43). However, highway agencies have little quantitative basis for establishing the optimum capacity rating criterion for their structures. An agency that chooses a more conservative criterion presumably obtains savings from extending the useful life of certain bridges and from reduced the risk of bridge damage, but at the cost of reducing the road network available for freight transportation. No bridge cost model is available for evaluating the costs and benefits involved in this trade-off.

The differences among the cost estimates arise from the following differences in the assumptions of the calculations:

- The method used to determine the flexural load-carrying capacity of each bridge in the road system and the evaluation (or lack of evaluation) of shear capacity.
- The rating method and associated factors assumed in determining which bridges would require replacement or posting.
- The unit costs of bridge construction. As previously noted, the study for AASHTO that recalculated bridge costs for the vehicles of the 2016 USDOT study (Wassef 2017) reported large variation in cost estimates depending on assumptions about unit costs. Data for accurately estimating unit costs are not readily available.
- The extent of the road system on which the new configurations are assumed to be authorized, especially whether minor roads are assumed to be exposed to heavier trucks and whether it is assumed that bridges on minor roads will be strengthened or replaced.
- Costs other than bridge replacement that some studies consider and others omit:
    - Repair of welds due to bigger stress cycles (that is, fatigue) in steel bridges.
    - Deck deterioration.
    - Deterioration or lost useful life in main longitudinal load-carrying members.
    - User costs (that is, delay from bridge construction and bridge posting).
    - User costs and costs of bridge impacts during the transition period between enactment of the new limits and completion of necessary improvements to the bridge system.
    - Cost to construct future bridges to higher standards.
- Assumptions about highway agencies' decisions regarding replacement versus posting. The past USDOT studies' estimates assume that all bridges adequate for existing legal limits but deficient for new limits are replaced.

To illustrate the uncertainty introduced in estimates by assumptions about highway agency practices, the TRB Commercial Motor Vehicles committee asked a state highway agency to evaluate four structures in the state, selected because they were among the structures with the highest replacement costs in the 2000 USDOT study's cost estimates. The agency reported that according to its normal practices, it would not replace, strengthen, or post load limits for any of the structures if the new vehicles evaluated by the USDOT study came into use. The agency also reported that, although it would not treat the bridges as the USDOT cost estimates assumed, the heavier vehicles would nonetheless increase costs by reducing the useful lifetimes of structures (TRB 2002, 64–66). The TRB Turner truck study, attempting to describe more realistically how states would respond to a change in limits, estimated costs in a range of scenarios in which some bridges are posted rather than replaced and replacements are phased in over a period of years (TRB 1990b, 153–156, 191–194).

National Cooperative Highway Research Program Report (NCHRP) 495, *Effect of Truck Weight on Bridge Network Costs* (Fu et al. 2003), developed and demonstrated methods of estimating certain bridge-related costs, but not all costs, on the basis of models of the physical effects of truck loads on bridge elements. Results of the study include the following:

- Four categories of impact were considered: fatigue in existing steel bridges, fatigue in existing reinforced concrete decks, deficiency due to overstress for existing bridges, and deficiency due to overstress for new bridges. Cost estimates for fatigue in steel bridges and fatigue in concrete decks are based on physical models of fatigue. Estimation of user costs was not within the study's scope.
- The cost for bridges with deficient girders was shown by examples to be the dominant contributor to systemwide costs from the existing inventory of bridges. There are few effective methods to strengthen existing concrete bridges to significantly increase the load rating. The alternatives are posting load limits for the bridge, barring use by larger trucks, or replacing it.

- The study concluded that increasing truck axle weights or increasing the frequency of truck axle loads would exacerbate the deterioration of bridge decks, independent of the effects of deicing agents.
- One example of the methods developed in the study estimated the cost of impacts on selected bridges of increasing the gross weight limit in one state from 105,000 lb to 129,000 lb (Fu et al. 2003, B-1–B-18, B-46) For alternative assumptions about truck operators' configuration selections in response to the change in limits, deck cost was at most 4 percent of total cost, in a case that assumed greater use of seven-axle triple trailers. Deck deterioration cost was estimated to decline in a case that assumed substitution of nine-axle for five-axle configurations. The major cost in both cases was estimated to be the added cost of constructing future new bridges to carry the increased load.

The 2016 USDOT report stated: "The most prevalent method used in the United States in the past decade (1997–2012) has been the 'Federal Method,' as described in the 2003 *NCHRP Report 495—Effect of Truck Weight on Bridge Network Costs*…" (FHWA 2016f, 5). The investigators chose not to use the method in the 2016 study (FHWA 2016f, 5). Future truck size and weight studies should compare the results of new methods to results produced by the methods of past studies, to clarify the sources of differences in impact estimates from study to study and to verify that the new methods are indeed advancements.

To overcome the major uncertainties in bridge cost estimates, two kinds of research would be required. First, research would be needed to develop methods to estimate bridge costs based on realistic assumptions about highway agency unit costs and likely agency responses to changes in truck traffic, as determined by observing state practices.

The second line of research would quantify the physical effects of a change in truck loads on bridge performance, that is, effects on rates of deterioration of decks and other components, service life, and main longitudinal load-carrying member or system strength. These relationships are needed in a truck size and weight study to estimate the costs of exposure to larger vehicles of structures that are not posted or replaced. The relationships are also needed to estimate the costs of alternative thresholds for making decisions on posting or replacing structures (for example, how costs would change if states adopted more permissive posting criteria to allow more widespread use of newly legalized configurations).

A research program made up of the following seven projects would contribute to meeting these needs and would provide USDOT and others with more credible methods for projecting bridge-related costs of changes in truck size and weight limits:

B1. Compile information from state and local highway agencies on costs and treatment selection criteria for bridge deck repair, rehabilitation, and replacement and for bridge span strengthening and replacement.

B2. Develop a model of the effect of wheel loads on bridge deck deterioration and resulting service life, supported by field performance data.

B3. Develop models of the effect of changes in truck size and weight on the most common bridge types, including the effect on service life of the main longitudinal load-carrying members or systems.

B4. Develop a method for estimating the effect of changes in truck size and weight limits on life-cycle costs of bridge decks, including user costs, and for considering the diversity of maintenance practices among state and local highway agencies.

B5. Develop a method for estimating the effect on bridge life-cycle cost of the change in deterioration and service life and in the risk of loss of functionality caused by a change in truck size and weight limits.

B6. Develop a replacement for the “Formula B” provision in federal size and weight law that more appropriately controls weights of short, heavy vehicles.

B7. Develop a revised deck design load and permit design load and calibrate load factors for both. Calibrate load factors for bridge evaluation that account for varying levels of law enforcement.

Problem statements for each of these topics appear in the following section.

BRIDGE RESEARCH PROBLEM STATEMENT B.1

Compile information from state and local highway agencies on costs and treatment selection criteria for bridge deck repair, rehabilitation, and replacement, and for bridge strengthening and replacement.

Problem Statement

Changes in truck size and weight limits may influence bridge deck maintenance and replacement, bridge posting, and the need to strengthen bridge spans. Costs for these activities vary greatly from region to region according to availability of materials, labor, design standards, average daily traffic (ADT), and detour lengths. Decision making at the local level is so varied that the risk of inconclusive results in projections of costs of changes in limits is high. Some agencies are well funded and well staffed, perform preventative maintenance on a regular basis, aggressively pursue funding, and contract to replace structurally or functionally obsolete bridges. Others are only able to perform the minimum federal inspection requirements and carry out little to no routine maintenance.

Research Objective

The objective is to obtain a quantitative description of the frequencies, expenditures, average construction costs, average user costs, and motivations for bridge owners to (1) undertake bridge deck repair, rehabilitation, and replacement and (2) strengthen, reconstruct, or replace bridges with insufficient strength in one or more spans.

Possible Approaches

The research requires developing a plan to obtain information and data on bridges and on bridge construction and maintenance projects from states and counties that adequately represent the national inventory of bridges. It may be appropriate to develop one dataset for studying bridge decks and another for investigating bridge spans, posting, and strengthening.

The research would entail a survey of states. To limit the cost and burden on participants, the survey could be conducted with a sample of states that agreed to participate and for a sample of bridge projects within each state. The steps in the analysis could be as follows:

1. Each participating highway agency would be asked to provide a list of all bridge strengthening, reconstruction, and replacement projects conducted over a period of years that were motivated at least in part by concerns for damage or structural deficiency in any element of the bridge, and the cost of each project. Records on all bridge postings during the period would also be obtained.
2. Samples of projects of each type would be selected from the list for investigation. For these bridges, the highway agency would be asked to report:
   - A description of the scope and elements of the project.
   - A description of the conditions that motivated the project.
   - A description of how the method of treatment was selected and of alternative treatments considered.
   - Project costs.
   - Duration of bridge closures and lane closures and user cost estimates, if available.

3. From the sample of bridges, average total project cost by size and type of bridge would be computed for replacement and for strengthening. Average duration of bridge closures would be similarly computed.
4. Any elements of the strengthening and replacement projects not related to eliminating the structural deficiency that motivated the project would be identified. For example, a replacement bridge may have been longer than the original bridge in order to straighten the approach alignment, or wider to increase capacity or improve safety. The research would estimate the benefits of such design upgrades for the bridges in the sample, using standard benefit–cost factors. In the case of a bridge replaced as a result of an increase in size and weight limits, these benefits would be an offset to the cost of the bridge attributable to the change in regulations.
5. The relative frequencies of strengthening and replacement in the sample projects would be tabulated by bridge type and age, traffic, and nature of deficiency. On the basis of the sample, the researcher would propose decision rules that identify the circumstances (for example, bridge type, age, traffic, nature of deficiency) in which a bridge is more likely to be strengthened or more likely to be replaced.

Data Requirements

The unit costs for the required bridge projects can be obtained from bridge owners. Bridge detour lengths can be obtained from the National Bridge Inventory (NBI) and used for the calculation of user delays.

Present Status of Research

Numerous past studies have developed empirical highway bridge cost estimating models, although many are more detailed than would be required or practical for the proposed research. Cost models are reviewed in Kim et a. (2009).

A study in progress is developing a method for estimating highway bridge construction time and costs based on historical projects:

> Minnesota Department of Transportation. *Bridge Construction Time and Costs*. http://dotapp7.dot.state.mn.us/projectPages/pages/projectDetails.jsf?id=17868&type=CONTRACT.

Bektas and Albughdadi (2018) provides insights to the causes of bridge replacements and to highway agency treatment decisions.

Estimated Cost and Research Period

Labor requirements:

> Recruitment of participating states and counties; identification of available project documentation: 4 person-months.
> Selection of sample projects and compilation of project data: 10 person-months.
> Data analysis: 4 person-months.
> Reporting: 3 person-months.

Duration: 18 to 20 months
Cost: $350,000 to $400,000

Priority

Uncertainty and inaccuracies in bridge construction cost estimates have been a major source of overall uncertainty in past truck size and weight studies. Counties and local agencies have often been omitted. Decision-making criteria have a large impact on actual expenditures, but vary from owner to owner. Therefore, this research could contribute to improving estimates of costs of changes in limits. However, because of the complexity of the decision-making setting, developing a method to reliably project highway agency responses to a change in federal regulations would be a challenging task.

A nationwide survey of practices for bridge strengthening versus replacement may be of general value to highway agencies for benchmarking their own bridge management practices.

BRIDGE RESEARCH PROBLEM STATEMENT B.2

Develop a model of the effect of wheel loads on bridge deck deterioration and resulting service life, supported by field performance data.

Problem Statement

Reinforced concrete bridge decks deteriorate over time due to vehicular load history, the environment, and human actions such as the use of deicing salts. Complicating factors include: initial workmanship, inherent durability of concrete materials, flexibility of the deck relative to the supporting girders, degree of fixity between the deck and girders, and level of transverse prestressing (if any) within the concrete bridge deck.

A comprehensive model of the relationship of cumulative truck wheel loads to reinforced concrete bridge deck deterioration (isolated from environmental effects), supported by field performance data, does not exist. Laboratory test results have been reported using small-scale component models; however, the model boundary conditions do not always account for the actual degree of fixity between the girders and deck. In addition, laboratory models have not accounted for the presence of prestressing or post-tensioning of the concrete. This prevents a reliable estimation of bridge deck cost impacts due to truck weight limit changes.

Research Objectives

The objective of this research project is to develop a model for reinforced, prestressed, and post-tensioned concrete bridge decks in the United States that quantifies the relationship between wheel load, design details, and service life. The model must account for size of the tire patch, axle spacing, and load history and be supported by field performance records. The research should demonstrate the relevance of the model as a method for projecting the impact of truck size and weight limit changes more realistically and credibly than previous models.

Possible Approaches

The research would develop a model to associate the deterioration and fatigue of concrete materials with repetitive heavy wheel loading. This model may be usable in finite element analysis. A method for calculation of punching shear resistance is also needed.

The following are three very different possible approaches:

1. Develop a mechanistic model similar to that developed for prediction of chloride ingress due to diffusion.
2. Use the NBI deck condition ratings over the years coupled with maintenance records to develop a machine-learned algorithm to predict service life.
3. Use condition assessments made with advanced sensing technology, such as Lidar, coupled with maintenance records to develop a method for predicting service life.

A necessary step in the research would be to identify typical deck deterioration modes. Typical modes of deterioration will depend on bridge type and climate region. Identification of deterioration modes is important for the specification of input parameters of deterioration models .

To verify the methodology developed, a procedure analogous to the steps outlined in problem statement B.3 could be followed: assemble a database for a sample of bridges in selected states, using traffic data and bridge condition data for a period of years assembled from existing WIM and bridge inspection data, and then compare model predictions to the actual historical experience.

Data for verification would be for bridges in nonmarine environments and not subjected to deicing salts, in order to isolate load-induced effects. Verification should include a wide range of deck-to-girder stiffness ratios and connectivity details.

Data Requirements

The data used in the research may include deck design and performance data from owners and from the NBI and truck weight data from WIM installations.

Present Status of Research

Fu et al. (2003) developed a deterioration model using laboratory test results from scaled reinforced concrete bridge decks in the United States and Japan. Lin et al. (2012) developed a model for the relationship of truck traffic volume and weights to deck deterioration on the basis of laboratory tests and simulation.

Modes of deck deterioration are characterized in Gucinski et al. (2013).

Lou et al. (2016), Nassif et al. (2015), and Al-Qadi et al. (2017) demonstrated methods of projecting deck deterioration as a function of axle loading, using relationships empirically calibrated with NBI bridge condition data and truck weight data from WIM installations. Gungor et al. (2018) developed a machine learning method to estimate the change in expected bridge deck service life caused by a change in truck loadings, using WIM and NBI data.

The application of Lidar to bridge condition data collection has been demonstrated by Liu (2010) and Liu et al. (2011).

Estimated Cost and Research Period

28 to 32 months
$300,000 to $450,000

The cost will depend on the kinds of research included in the study design. Laboratory testing would add to the cost but may not be essential. The cost of collecting and analyzing field performance data will depend on whether this task can be combined with other research assembling truck traffic and infrastructure data (such as the research outlined in problem statements C.1 and B.4).

Priority

This research project is expected to significantly reduce the uncertainty in the incremental cost estimation for concrete bridge deck consumption as a function of truck weight limit change.

Models of deck deterioration may also have applications for bridge management and improved bridge deck design, independent of their usefulness for evaluating truck size and weight limits.

BRIDGE RESEARCH PROBLEM STATEMENT B.3

Develop models of the effect of changes in truck size and weight on the most common bridge types, including effect on service life of the main longitudinal load-carrying members or system.

Problem Statement

An increase in the weights of trucks using a bridge, and especially, increased exposure to loads greater than those the bridge was designed to carry, may reduce the useful life of the main longitudinal load-carrying members or system. In addition, a single exposure to a load greatly exceeding the design limit slightly risks immediate damage that renders the bridge unserviceable. The costs of these impacts will depend on decisions of highway agencies to post, replace, strengthen, or leave unaltered potentially vulnerable bridges.

The variability in bridge posting practices among the states indicates a need for better quantitative understanding of the effects over time of exposure of bridges to truck loadings. Highway agencies post bridges when heavier vehicles would surpass a threshold of acceptable risk, or because repeated exposure would cause progressive damage judged to be unacceptable. States with relatively restrictive posting criteria presumably intend to avoid costs by extending bridge life, but the magnitude of the highway agency and user cost differences between more restrictive and less restrictive standards is unknown.

Research Objective

This research would develop models of the effect of changes in loadings on the service life of bridge elements other than decks, as the basis for estimating bridge-related costs of changes in truck size and weight limits. The research should demonstrate the relevance of the models as a method for projecting the impact of truck size and weight limit changes more realistically and credibly than previous models.

Possible Approaches

An empirical model for projecting the effect of a change in truck loadings on the service life of the structural elements of bridge could be developed by assembling a database for a sample of bridges in selected states, containing traffic data and bridge condition data for a period of years, from existing WIM and bridge inspection data. The model would be specified according to engineering theory and the model parameters estimated from the database.

The research would consider the 10 most common bridge structure types. Useful life varies according to structure type. The most common types are (roughly):

1. Concrete slab bridges.
2. Conventionally reinforced concrete girder bridges and rigid frames.
3. Precast, prestressed concrete slabs.
4. Prestressed I-Beams and Bulb-Tees.
5. Prestressed box beams.
6. Posttensioned concrete box girders.
7. Rolled or fabricated steel-beam multigirder bridges.
8. Steel two-girder systems.
9. Steel trusses.
10. Steel box beams and orthotropic girders.

An analysis using existing data could proceed in the following steps:

1. Identify a representative number of states (possibly 8 to 12) with relatively high-quality WIM data (that is, a relatively dense network of sites with relatively complete and reliable records for a period of years) and high-quality bridge inspection data (from the NBI and possibly also more detailed data from the state's bridge management system) that agree to participate in the research. Each of the common bridge types must be adequately represented among the collective bridges of the selected states.
2. Develop estimates of the loads applied to the selected sample of bridges in each state. The research would assess at least two methods for estimating loads: (a) by individually matching a state's WIM sites to bridges near enough to a WIM site that traffic at the WIM site would be nearly identical to traffic at the bridge (for example, WIM site-bridge pairs with no intersecting road with significant truck traffic between the WIM and the bridge) or (b) by approximating truck traffic volumes and axle weight distributions over the entire network as a function of weights at the WIM sites (for example, by the method of Al-Qadi et al. 2017, 35–38).

   Load-induced deterioration will depend on cumulative loads since construction of the bridge. Weight and truck traffic data since construction are unlikely to be available for most bridges. The research will test alternative methods of estimating cumulative loadings based on available weight and traffic data.
3. Create a cross-section or time-series database with each record corresponding to one bridge in 1 year and including data on location, age, condition measures (from NBI and bridge management systems), design characteristics, repair history, and truck traffic volume and axle and axle group weight spectra.
4. Specify the form of the expected relationships of condition to bridge characteristics and load history, based on engineering theory (for example, Nassif et al. 2015, 69–77). Apply the database to estimate model relationships. Specification of the models will require identifying the typical deterioration modes of the load-carrying members or system for each structure type.

If a large database of historical bridge condition and truck traffic data is created, a machine learning technique may be the most productive method to identify relationships of bridge condition and condition trend to bridge characteristics (for example, bridge type, girder spacing, past treatments, environmental conditions) and truck traffic characteristics.

Data Requirements

The data required are condition measurements and traffic loading data for a sample of bridges over a period of years. The dataset must be statistically representative of U.S. bridges.

If the sample of bridges is selected by choosing bridges that can be matched with nearby WIM installations, the sample will not be random. The analysis should take this possibility into account. Weight data collection using portable WIM could avoid bias related to the location of fixed WIM installations.

Present Status of Research

Empirical modeling of the effect of truck traffic characteristics on the service life of steel and prestressed concrete bridge girders is described in Lou et al. (2017) and Nassif et al. (2015, 70-77).

Bridge failure probability modeling is described in Proske (2018).

Estimated Cost and Research Period

For the approach previously outlined:

Labor requirements: 48 person-months
Duration: 28 to 36 months
Cost: $750,000 to $1,200,000

Priority

Several past truck size and weight studies have identified the cost of protecting bridges from damage or deterioration as the largest potential cost of changes in size and weight limits, but have not used satisfactory methods for estimating these costs. Therefore, the topic of this research merits high priority.

The value for highway agency bridge management of improved understanding of the relationship of truck traffic characteristics to structural deterioration is further strong justification for the research.

Models developed using only currently available data will be very approximate. Eventually, the FHWA Long-Term Bridge Performance Program may provide more suitable data.

BRIDGE RESEARCH PROBLEM STATEMENT B.4

Develop a method for estimating the effect of changes in truck size and weight limits on life-cycle costs of bridge decks, including user costs, and for considering the diversity of maintenance practices among state and local highway agencies.

Problem Statement

The deck deterioration and structure deterioration models, unit cost data, and synthesis of state decision-making practices developed in the research outlined in problem statements B.1 and B.2 would supply the tools to make credible projections of bridge-related costs in a truck size and weight limits study. Research is needed to define and test a procedure for such an analysis.

Research Objective

The objective of this research is to develop a method of projecting the change in bridge deck maintenance, rehabilitation, and replacement costs caused by changes in truck size, axle loads, axle configurations, and frequency.

Possible Approaches

The research could proceed in the following steps:

1. Create a dataset of bridge decks that is representative of those on Interstates, highways, and local roads nationwide and for which information is available on design, previous maintenance and rehabilitation, past inspection records, and traffic history. The sample should also be representative of the national variety in concrete deck strengths, amount of bar reinforcement, deck stiffness relative to supporting members, and degree of fixity, deck thickness, and flexibility.
2. Categorize the sample according to the owner’s ability and likelihood to perform preventative maintenance, frequency of maintenance, and likely rehabilitation schemes, according to the results of the research of problem statement B.1.
3. Apply the deck service life model of problem statement B.2 to each bridge in each category of preventative maintenance. Estimate service life and associated life-cycle cost for each bridge, taking into account the owner’s maintenance and rehabilitation practices.
4. Estimate associated user delay costs according to the volume and mix of traffic on each bridge.
5. Assume a hypothetical change in future truck traffic volume and axle weight distribution caused by a change in truck size and weight limits, repeat the cost calculation for each bridge, and calculate the cost difference with respect to the base case. The traffic change could be taken from projections of the USDOT 2016 or 2000 truck size and weight studies.
6. Extrapolate the deck life-cycle cost estimates from the dataset to all bridges nationwide.

Since the objective of the research would be to develop a generally applicable method for future studies, the product would be a manual and a set of models.

Data Requirements

The required information for the sample bridge decks would be obtained from bridge owners. Available and applicable WIM data may be limited.

Present Status of Research

Examples of estimates of deck-related costs of changes in size and weight limits are found in Al-Qadi et al. (2017), Lou et al. (2016), Nassif et al. (2015), and Fu et al. (2003). The logic of these estimates is similar to the steps previously outlined, although various models and data sources are used.

Estimated Cost and Research Period

18 to 28 months
$300,000 to $450,000

Priority

Past evaluations of truck size and weight limit changes (for example, USDOT 2000, VI-1) have assumed that bridge deck costs would not be a significant consequence of changes that do not involve changes in axle weight limits. Deck costs should be estimated carefully to test this assumption. However, the improved physical model of B.2 is the critical bridge deck evaluation need.

BRIDGE RESEARCH PROBLEM STATEMENT B.5

Develop a method for estimating the effect on bridge life-cycle cost of the change in deterioration and service life and in risk of loss of functionality caused by a change in truck size and weight limits.

Problem Statement

The research outlined in problem statement B.3 would develop a model for each common bridge type of the effect of an increase in the weights of trucks using a bridge on the loss of useful life of the bridge through deterioration of bridge elements other than the deck. This model, together with the unit cost data and synthesis of state decision-making practices developed in the research outlined in problem statement B.1, would provide a method to project bridge-related costs (other than deck-related costs) of changes in size and weight limits and to evaluate strategies for limiting these costs. Research is needed to define and test a procedure for such an analysis.

If legal truck size and weight limits were increased, bridge owners would review their bridge inventories to identify needed responses. Bridges on frequently used truck routes that were unable to carry the increased loads would be prioritized and programmed for strengthening or replacement, followed by those less frequently used. Bridge posting would restrict truck traffic on bridges determined to be structurally inadequate but not of high priority for replacement. Users would bear the delay costs of construction and detours. Bridges that do not receive any treatment and are not posted may experience accelerated deterioration.

Research Objective

The research would develop and demonstrate a method to project the following costs of a change in truck size and weight limit:

- Bridge strengthening and replacement undertaken in response to the change in limits.
- Accelerated deterioration and loss of service life of bridges not replaced or strengthened.
- User delays caused by bridge postings and construction resulting from the change in limits.

The method developed in this research would complement the method for deck cost estimates developed in the research of problem statement B.4.

Possible Approaches

The research approach would be analogous to the approach for estimating bridge deck costs outlined in problem statement B.4.

A dataset of bridges used for the research should be nationally representative of the 10 to 12 most common bridge types, age distribution, length of spans, rural versus city location, and state versus local ownership. As an alternative, the Long-Term Bridge Performance (LTBP) Program has established a concept of bridge clusters.

The bridges would be rated to identify the bridges that highway agencies would determine to be candidates for posting or for eventual strengthening or replacement in alternative size and weight limit scenarios. The more critical of bending and shear ratings should be considered. Posting practices vary from state to state and need to be accounted for.

Each bridge would be paired with the owner's likely strengthening strategy and criteria for deciding when a total replacement would be undertaken. The threshold might vary for state versus local owners.

Costs of strategies undertaken must be assigned using local cost data. The aggressiveness of the bridge owner should be estimated and detour costs applied until projects are likely to be undertaken. The analysis would assume a time period and budget constraint for the bridge improvement program in each regulatory scenario. A realistic period may be 10 years.

The research could begin by developing cost estimation methods for a limited number of common bridge types likely to be vulnerable to increases in truck size and weight limits. If the initial effort was successful, the method could be expanded to additional bridge types. Bridge strengthening methods, and the practicality of strengthening, depend on the bridge type, complicating cost estimates for the entire inventory of bridges.

A key component of the research would be evaluating the effect on cost projections of alternative assumptions about highway agency bridge program responses to a change in size and weight limits. For example, cost projections could be carried assuming highway agencies all applied a strict overstress criterion in decisions on bridge posting and replacement, and alternatively that the criterion was relaxed to allow heavier trucks to operate more widely. The relative effects of the alternatives could be estimated for all relevant costs: user costs, replacement and strengthening costs, and lost service life of bridges not treated. Past truck size and weight studies were unable to make such comparisons because they lacked a model for costs of deterioration of bridges that were not strengthened, replaced, or posted.

Data Requirements

The required information for the sample bridges would be obtained from bridge owners.

Present Status of Research

Nassif et al. (2015) and Fu et al. (2003) present estimates of the costs of allowing heavier trucks that include some of the features of the research proposed in this problem statement.

Estimated Cost and Research Period

20 to 30 months
$350,000 to $500,000

Priority

As described in the introduction to the bridge research problem statements, the variability of estimates of costs related to bridge structural inadequacy has been a major weakness of the cost estimates of past truck size and weight studies. The research outlined in this problem statement (which depends on research outlined in problem statements B.1 and B.3) would provide more defensible estimates because it would be based on more complete information about highway agency decision making and because it would show the consequences for all costs (loss of service life, replacement and strengthening costs, and user costs) of alternative assumptions about the decisions that highway agencies would make about posting or replacing bridges if limits were changed. The improved physical models of problem statements B.2 and B.3 are the critical bridge service life evaluation needs.

BRIDGE RESEARCH PROBLEM STATEMENT B.6

Develop a replacement for the "Formula B" provision in federal size and weight law that more appropriately controls weights of short, heavy vehicles.

Problem Statement

Formula B is a mathematical equation, table, and series of footnotes that make up part of the federal weight and size regulations about interstate commercial traffic on bridges. It became law in 1974 and is based on stress limits in single-span bridges. An unintended consequence of the formula was the proliferation of short, heavy trucks (referred to as specialized hauling vehicles or SHVs) that were designed to satisfy Formula B but that induce force effects that older bridges were not designed to resist.

The formula is out of date in terms of current truck configuration, inconsistent for truck operators, contrary to current bridge rating legislation, and fails to adequately protect highway infrastructure.

Research Objective

The objective of this research is to create a practical replacement to Formula B. Span continuity and negative bending and shear force effects must be considered. In addition, the transverse distribution of loads (tires per axle or tire width) must be considered, as well as the number and spacing of axles in the longitudinal direction.

Possible Approaches

The potential impact of the proposed replacement must be tested by:

- Anticipating which vehicle configurations are likely to be developed to pass the new formula, and
- Using bridges from the NBI database to determine the estimated number of bridges needing strengthening or replacement. The number should be compared and contrasted to the estimated number of bridges needing strengthening or replacement due to current legal loads, including SHVs and emergency vehicles (EVs).

Data Requirements

Data are required for bridge loads and bridge resistance. A survey of commercial carriers and state permitting practice may be of assistance in terms of loads“”. However, permutations of the SHVs and EVs now required for bridge rating may be more practical and sufficient. For bridge resistance, a cross-section of bridge types and span lengths is needed that is representative of state and local bridge inventories nationwide. Formula B was based on single spans only; multispan structures must be used. The NBI may be sufficient. The LTBP program bridge clusters may help in achieving a good representation. Conversely, this effort might contribute to the LTBP database of bridge clusters depending on its status at the commencement of this research.

Present Status of Research

A 1990 TRB committee evaluated alternatives (TRB 1990a). None was adopted. FHWA's 2006 pamphlet "*Bridge Formula Development*" sheds light on one option. Recently, FHWA revised the Formula B footnote listed in the pamphlet to a simpler more general statement "all bridges must be inspected, rated to safe load-carrying capacity and if required, posted or restricted with respect to the maximum allowable weight." This obfuscates the fact that Formula B fails to stop SHVs for which many county, local, and rural roads were not designed.

Estimated Cost and Research Period

Six months would be required to develop, select, and test an approach. An additional 18 months would be required to document, test, and perfect the product. The estimated cost is $300,000 plus the cost of structural analysis software.

Priority

This study will reduce the uncertainty regarding force effects of current truck configurations on bridge superstructures. Less uncertainty will improve asset management decisions. The results will provide guidance on regulatory adjustments to more effectively control infrastructure costs. Greater equity in goods movement and law enforcement will result.

BRIDGE RESEARCH PROBLEM STATEMENT B.7

Develop a revised deck design load and permit design load and calibrate load factors for both. Calibrate load factors for bridge evaluation that account for varying levels of law enforcement.

Problem Statement

The current AASHTO bridge design specifications (AASHTO 2017) require deck design for a 32,000-lb. axle load. WIM data studied in NCHRP Report 683 (Sivakumar et al. 2011) show that axle loads can be much higher. The design methodology does not take advantage of analytical tools now commonly available. The load factor is calibrated for force effects in girders; it does not account for the variability in axle loads or the effectiveness of law enforcement.

The AASHTO bridge design specifications provide a generic load combination for permit trucks to be used with a state- or owner-specified design permit truck. Since design and permit rating trucks vary from state to state, operators must often reconfigure their trucks at the state line. The load factor for the permit truck load combination has a generic value of 1.35. This may be excessive to those states able to strictly control their overloads but insufficient for locations prone to illegal loads.

Revised design loads are needed to accommodate present actual loads. Revised design loads would also be needed if a change in truck size and weight regulations led to the introduction of new truck configurations for bridge design and for evaluating the capacity of existing bridges.

Introduction of truck platooning would present a problem analogous to the introduction of a new configuration, in that platooning would expose bridges to loads and axle configurations not considered in present bridge design or truck permitting procedures. Representative design loads would be required to evaluate platooning operations.

Research Objectives

The objectives are to develop:

1. Deck design load or loads that
   a. Accommodate EVs and SHVs now required for bridge rating.
   b. Reflect current WIM axle load data.
   c. Consider tire configurations, if beneficial.
2. A practical but improved design methodology for conventionally reinforced, prestressed and post-tensioned concrete decks.
3. A new deck design load factor or factors. The load factor must be scalable for varying risk of overload.
4. A national design permit truck.
5. New permit truck load factor for the AASHTO bridge design specifications' Strength II load combination. The load factor or factors must be scalable for varying risk of overload.
6. Design loads and load factors needed for the evaluation and design of bridges carrying truck platoons.

Possible Approaches

A nationally representative sample of WIM data is required. This data would be available from the research outlined in problem statement C.1. Truck configurations, axle load, and frequencies of each can be compiled and compared to SHV axle load configurations now required for bridge rating, as well as potential increased truck legal loads.

A new deck design methodology might use tabularized deck-girder stiffness ratios to adjust design for potential deflections and also add thickness or reinforcement requirements for shear.

Calibration should apply methods used for calibration of other loads in AASHTO bridge-related specifications and guide specifications.

Data Requirements

WIM and corresponding law enforcement data. Datasets of bridges unless Monte Carlo simulation methods are used.

Present Status of Research

WIM data collection and analysis for bridge design is addressed in Sivakumar et al. (2011). Calibration of load and resistance factors is addressed in Kulicki et al. (2007).

The European Union in 2018 began a of truck platooning, the ENSEMBLE Initiative, which is to include assessment of the impact of platooning on bridges as well as other infrastructure, environmental, and economic effects (Hoedemaeker 2018).

Estimated Cost and Research Period

30 months
$300,000

Priority

This research project is needed in response to increased truck size and weight for the appropriate design of girders and decks in new bridges. Improvement of deck design methodologies is ancillary but could lead to justification of higher axle loads. Although the research has a high likelihood of success, it may follow other efforts required for increased truck size and weight.

SAFETY RESEARCH

The safety impact of a change in truck size and weight regulations is the change in the frequencies of crashes and crash casualties occurring on the highway system resulting from the change in the regulations. Crash frequency may change because the volume of truck traffic and the distribution of truck traffic across the road system change and because new truck types may have inherently different crash risk per mile of travel than the trucks they replace. Projecting the safety impact requires estimating the combined effects of changes in traffic volume and crash rates on the systemwide frequencies of crashes and casualties.

The 2016 and 2000 USDOT truck size and weight studies identified safety impact as a critical uncertainty in projections of the consequences of changing the regulations. The 2016 USDOT study undertook estimates of comparative crash rates of alternative vehicles, but concluded that the information was insufficient to support a conclusion about the nationwide safety impact of changing limits (FHWA 2016a, 18). The 2000 USDOT study similarly declined to project safety impacts (USDOT 2000, ES-8–ES-10).

Earlier studies did produce quantitative estimates of safety impacts. The 1981 USDOT study attempted to measure the crash rates of alternative vehicles and presented two impact estimates for two values of the ratio of crash rates of single-trailer and double-trailer combinations (USDOT 1981, II-20–II-22). The TRB study committees synthesized published estimates of comparative crash rates to select rates, or ranges of rates, that were used to compute systemwide safety impacts of changes in the regulations (TRB 1986, 150–153, 304–329; TRB 1990a, 125–133; TRB 1990b, 129–130, 180–181).

The past estimates of safety impacts have been based on truck crash involvement rates (crash involvements of a specified severity per million vehicle-miles of travel) measured directly from crash records and estimated vehicle-miles of travel by truck type over a road system. The experience indicates that obtaining credible, generalizable estimates by this method is extremely difficult, for three reasons. First, the routinely collected data on crashes and on truck travel lack the detail and reliability needed for the estimates. Second, the factors that influence crash risk are complex. Crash risk is known to vary with road class, time of day, weather, terrain, traffic, driver characteristics, motor carrier characteristics, and other factors, which must be controlled for in a statistical analysis to isolate the effect of truck configuration or weight. Finally, changes in truck size and weight limits may bring into use new vehicle types or new kinds of trucking operations that have no historical record of safety performance.

A research program made up of the following projects would lead to better understanding of the effect of truck size and weight on crash risk, support safety analyses in truck size and weight studies, and support evaluation of ways to reduce crash risks:

S.1 Enhancement of crash and exposure data for application in a research environment.

S.2 Comparative evaluations of differences in safety performance among truck configurations by measurement of crash involvement rates on a network of roads.

S.3 Comparative evaluations of differences in safety performance among truck configurations by the case-control method.

S.4 Comparative evaluations of differences in safety performance among truck configurations by measurement of crash involvement rates using trucking company data.

S.5 Evaluation of potential safety performance of truck configurations with computer simulation modeling and track testing.

S.6 Relation of crash risk on a road to vehicle mix and traffic volume.

The following analysis of the difficulties encountered in past measurements of comparative crash risk serves as an introduction to the research problem statements.

Comparative evaluations (such as are proposed in research problem statements S.2, S.3, and S.4) are studies to compare the crash involvement rates of two or more truck types using data on truck crashes and truck travel in a specified area or road network within a specified period. Numerous and substantial challenges threaten the validity of comparative safety evaluations of truck configurations in current use on U.S. roads. These include:

1. Lack of crash data that include accurate classification of the truck configurations for crash-involved trucks.

2. Lack of crash data that include accurate measurement or estimate of the gross weight for crash-involved trucks.
3. Lack of data on the volumes and vehicle-miles of travel for trucks of specific configurations.
4. Lack of data on the distribution of gross weights for all trucks of specific configurations.
5. Bias due to undocumented differences in the roads traveled, times of day operated, commodities transported, truck design details, and levels of driver experience among the truck configurations being compared.
6. Lack of a sufficient sample of crash and exposure data for each truck type of interest to draw meaningful, statistically significant conclusions.

Potential Bias Due to Lack of Specific Data Types (Limitations 1 Through 4)

Limitations 1 through 4 reflect the current nature of data systems in most states. Investigating officers at crash sites often lack the knowledge or training to accurately classify truck configurations and seldom have access to data on truck weights. Truck exposure (vehicle-miles of travel) data collection systems are limited in their ability to accurately identify truck classifications and weights. These limitations in crash and exposure data collection can be addressed with supplementary data enhancements for specific studies as described in problem statements S.1 and S.2. Ideally, crash and exposure data collection can be improved by using long-term monitoring systems that would enhance truck safety management and future comparative evaluation studies.

Potential Bias Due to Undocumented Variables (Limitation 5)

Comparative evaluations of truck types may easily become biased due to undocumented differences in the roads traveled, times of day operated, commodities transported, truck design details, and levels of truck driver experience between the truck configurations being compared. Some truck configurations (such as van-type tractors/semitrailers) are widely used for general commodities, while other truck configurations may have very specialized uses that are limited to particular roads, times of day, and truck body types.

Some truck configurations are driven by drivers with a wide range of experience levels, while other truck configurations may only be assigned to the most experienced drivers.

Failure to account for such differences will bias comparison of truck types in general use to truck types with limited or specialized uses. To provide accurate results, evaluations either must compare truck types in widespread, general use or must be structured to control for the influence of differences in use patterns among truck types.

Potential Bias Due to Lack of Sufficient Crash and Exposure Sample Sizes (Limitation 6)

To obtain accurate results, a comparative evaluation between truck configurations must have sufficient sample sizes for crash and exposure data for each truck configuration to provide statistically significant results. The smaller the actual difference in crash rate between the truck configurations being investigated, the larger the sample sizes of crash and exposure data needed to identify the difference in crash rates between the trucks in question.

Thus, if the actual difference in crash rate between two truck types is as large as 50 percent, relatively modest amounts of data can identify the difference as statistically significant. If the actual difference in crash rate between two truck types is small (for example, 5 percent or 10 percent), a much larger sample is needed. If the crash rate difference between two truck types is very small, it may be impractical to design a study that would be able to detect it.

A 1986 study for FHWA (McGee and Morganstein 1986) provides a methodology to estimate sample sizes needed for comparative evaluations. That study proposed selecting a national random sample of geographic areas (counties or county groups, the same sampling approach that NHTSA uses to collect nationwide motor vehicle crash data). Crash data would come from police reports that have a supplemental form for recording truck dimensions and operator characteristics. The database would include all crashes of the vehicles of interest in each sampled region during 1 or more years. Exposure would be estimated from special traffic counts on sample road segments in each sample region. The study estimated that a sample of 300 regions and 1 year of data collection (producing records for about 20,000 truck crashes) would be needed to detect a 15 percent crash involvement-rated difference between five-axle tractor semitrailer and five-axle twin 28-ft double trailer van body combinations with a 90 percent confidence level, or 500 regions (producing a database of about 35,000 crashes) to detect a 10 percent rate difference with a 90 percent confidence level.

A limitation of comparative evaluation methods based on crash and exposure data is that they are applicable only to truck types that actually operate on the road, either in general use or as part of a trial.

Summary

Given these threats to the validity of comparative evaluations, it is essential that comparative evaluations of truck configurations be carefully designed. It is unlikely that valid evaluations can be performed using only the data currently collected by and available from highway and law enforcement agencies. A valid study will likely require supplemental data collection. This could include data collection with the enhanced methods discussed in problem statement S.1, in-depth supplemental investigations of crashes such as those conducted for a case-control study, or supplementary data acquired from trucking companies under data sharing agreements.

No single comparative evaluation study will provide a definitive and comprehensive measurement of the relationship of truck configuration and weight to crash risk. The results of any study of such a complex phenomenon may be susceptible to distortion from flaws in execution or from effects of variables not taken into account in the analysis. Improved understanding of truck safety will come from the cumulative experience of studies using diverse methodologies, conducted in a variety of settings.

Results of vehicle dynamics simulation modeling and test track evaluations can be used to investigate possible sources of differences in safety performance among existing or proposed truck configurations. Indeed, for trucks that do not currently operate on U.S. roads, vehicle dynamics simulation modeling and test track evaluation may be the most desirable first step to characterizing the likely safety performance (see problem statement S.5).

Trial programs (see problem statement C.4) are a promising next step for evaluating the safety performance of proposed new truck configurations that appear likely to perform satisfactorily based on the results of vehicle dynamics simulation modeling or test track evaluations. Trial programs can provide data on crash characteristics for a truck configuration under evaluation.

SAFETY RESEARCH PROBLEM STATEMENT S.1

Enhancement of crash and exposure data for application in a research environment.

Problem Statement

A key limitation for comparative studies of the safety performance of truck configurations is the lack of complete and accurate data on truck-involved crashes and truck exposure (vehicle-miles of travel) for specific truck configurations. For comparative evaluations to be successful, crash records should accurately identify the configuration and gross weight of each truck involved in a crash, and exposure data should be sufficient to estimate vehicle-miles of travel and the distribution of gross weights of in-service trucks by truck configuration.

Research Objective

The objective of the proposed research is to develop and test methods for enhancing crash data with truck configuration and weight data for each crash-involved truck and methods for enhancing exposure data with data on the truck configuration and weight for each truck counted in traffic volume data collection. This research problem statement addresses the enhancement of crash and exposure data for defined roadway networks and periods in a research environment.

Possible Approaches

The research most likely would be organized as a project that recruits the cooperation of state departments of transportation, state highway patrol agencies, and local highway and police agencies. The research could also include tests of approaches involving private-sector cooperation in data collection. The participating organizations would agree to adopt specified data collection procedures for fixed periods. The researchers would design the data collection procedures in consultation with the organizations, train organization personnel, and monitor implementation of the procedures. The researchers would also define criteria for evaluating the data collection procedures and carry out data evaluations that consider the quality of the crash and exposure data obtained, practicality, and cost.

Enhanced crash data have been obtained in past studies by supplying investigating officers with a supplementary data form to be completed for each crash-involved truck and providing training for investigating officers on how to complete the form. Accurate classification of truck configuration is challenging. Greater accuracy might be obtained by having the investigating officer photograph each crash-involved truck, showing the tractors and trailer, their axles, and the connection between them. Researchers familiar with the nuances of truck configuration classification could then classify truck configurations.

Data on the gross weights of crash-involved trucks are almost never available to the investigating officer. Research is needed to assess alternative methods of obtaining gross weight data for crash-involved trucks. This could include:

- Locating weight records from an upstream weigh station through which the truck in question passed as part of the same trip.
- Locating weight records for an upstream WIM installation over which the truck in question passed as part of the same trip.
- Obtaining trucking company dispatching data that contain gross weight information.

Enhanced exposure data needs should be addressed by combining existing and new technologies. This could include, for example, the combined use of traffic counters (permanent loops or temporary sensors), WIM sensors, and cameras to photograph each truck.

Development of truck weight data for research purposes is a part of the proposed scope of research for problem statement C.1. If both this project and project C.1 are carried out, development of weight data collection methods would be a single activity conducted by one research team.

Data Requirements

The data elements that are not routinely or accurately collected for most crash and exposure databases include:

- Crash data elements:
  - Truck configuration for each crash-involved truck (based on number and length of tractor and trailer units, number and spacing of axles, and types of hitch connections between tractors and trailers).
  - Cargo body type for each crash-involved truck (enclosed van, tank, flatbed, etc.).
  - Gross weight for each crash-involved truck.
- Exposure data elements:
  - Truck configuration for each truck counted in exposure studies (based on number and length of tractor and trailer units, number and spacing of axles, and types of hitch connections between tractors and trailers).
  - Cargo body type for each truck counted in exposure studies (enclosed van, tank, flatbed, etc.).
  - Gross weight of each truck counted in exposure studies.

Present Status of Research

Several past studies have used supplementary forms to gather additional data on crash-involved trucks. It does not appear that a combined installation of traffic counters, WIM equipment, and vehicle photography has been developed and used for exposure data collection to obtain network-level or corridor-level estimates of truck exposure.

The American Transportation Research Institute (ATRI), a research organization supported by the trucking industry, announced in 2018 that it was undertaking research on truck crash data improvement in a project entitled “Assessing the Consistency and Accuracy of CMV Crash Data” (ATRI 2018). Joint government-industry efforts on some aspects of data system development may be possible.

The FHWA Office of Safety Research and Development’s pilot in-service performance evaluation of guardrail end terminals, in progress in 2018, provides a model for a crash risk evaluation study that collects crash data through a cooperative federal–state–local arrangement (FHWA 2018).

Estimated Cost and Research Period

The research could be conducted at various scales, ranging from a test of a single basic method of data collection involving a small number of cooperating jurisdictions to multiple tests of a range of approaches for obtaining crash and exposure data from public and private sources. The research could be limited to developing data for direct measurement of crash involvement rates (i.e., data for all crashes and for vehicle miles of travel by truck type on a network of roads) or could also include development of data collection methods for case-control studies.

A study to develop, test, and compare several alternative crash and exposure data collection approaches would cost on the order of $1,000,000 to $1,500,000 and require 18 to 30 months. A test of a single approach to crash data collection would cost approximately $450,000 to $650,000 over 16 to 24 months.

In addition to these funds, the research would depend on in-kind contributions of staff time and equipment from the participating agencies.

This study could be conducted as a component of a comparative evaluation conducted as outlined in problem statements S.2, S.3, and S.4. That is, data produced in this study could be the basis of an analysis of comparative crash risk.

Priority

If comparative evaluations between truck configurations are planned, particularly using route- or network-based approaches or case-control methods, the research described in this problem statement has a high priority as a prerequisite.

SAFETY RESEARCH PROBLEM STATEMENT S.2

Develop and demonstrate a method to conduct route-based or network-based comparative evaluations of the safety performance of truck configurations.

Problem Statement

Comparative evaluations are conducted to quantify the difference in safety performance measures (crash involvement rates and crash severity distributions) among truck configurations. Typically, a comparative evaluation would compare the safety performance of a baseline truck in widespread operation (such as a tractor-semitrailer truck with a single 53-ft. trailer or a double-trailer truck with two 28-ft. trailers) to one or more less common truck configurations (perhaps configurations that operate only in certain states or on certain roadway types).

Comparative evaluations can be conducted as required to evaluate specific configurations of interest or the safety of operation of a configuration on a particular category of roads. If USDOT chooses to develop a capability to conduct comparative evaluations as needed, the first such evaluations could be treated as trials to design and test a standard method.

Truck configurations may be defined in terms of numbers of trailers, trailer length, type of connection between units, and number and spacing of axles. The categories of vehicles to be compared could also be defined in terms of gross weight ranges.

Research Objective

This research would develop and demonstrate a method to compare the safety performance of specific truck configurations to provide a quantitative basis for projecting the safety impact of a change in truck size and weight regulations.

Possible Approaches

Three approaches to comparative evaluations are:

1. Route-based and network-based comparative evaluations.
2. Case-control comparative evaluations.
3. Comparative evaluations that use trucking company data.

This problem statement describes route-based and network-based evaluations. Problem statements S.3 and S.4 describe case-control evaluations and evaluations that use trucking company data, respectively.

Route-based and network-based evaluations require enhanced crash and exposure data (see problem statement S.1) because existing databases do not identify truck configurations accurately. Route-based and network-based studies must be structured to account for factors other than configuration that may affect crash risk, for example, cargo types, weight distributions, route characteristics, and driver experience levels.

The evaluation would proceed in the following steps:

1. Define the configurations of interest from among the configurations with substantial current use in the United States.
2. Identify road networks or regions where the configurations of interest are being used, for

potential locations of the study.
3. Collect crash and exposure data according to the methods developed in the research outlined in problem statement S.1.
4. On the basis of the data from the previous step and other sources, identify important potentially confounding variables that may bias comparisons among the configurations. Data on some control variables will be obtainable in the exposure data (for example, routes, body types, time of day of travel). Other confounding variables will be difficult to observe. For example, if two configurations being compared differ with respect to the industries in which they are used, differences among industries in driver characteristics and supervision, vehicle maintenance, or schedules may bias comparisons.
5. Apply statistical methods to estimate the effect of configuration type on crash involvement risk and casualty risk. Comparisons can be expressed as simple computations of average crash involvement rates by road class, with estimates of confidence intervals. As an alternative, a multivariate risk model could be estimated.
6. Demonstrate the application of the comparative evaluation results for projecting the safety impact of a change in truck size and weight regulations.

Data Requirements

The enhanced crash and exposure data are the primary requirements. In addition, data on the potentially confounding factors will be required. Sample sizes for comparative studies estimated by McGee and Morganstein (1986) were previously described in the introduction to the safety problem statements.

Present Status of Research

Numerous comparative studies of this kind have been conducted. The crash involvement rate estimates produced for the USDOT 2016 truck size and weight study are an example (FHWA 2015d, 18–26). The literature review for the USDOT study cites other examples (FHWA 2015d, 110–115). The TRB committee truck size and weight studies (TRB 1986, 1990a, 1990b, and 2002) also contained critical literature reviews of comparative safety evaluations.

Estimated Cost and Research Period

The cost of a study capable of measuring the differences among configurations of current interest in the United States would be on the order of $2 million to $5 million and would require 3 to 5 years. Cost and duration would depend on the data collection techniques and sample sizes of crash and exposure data. The sample size needed, and therefore the cost of the study, increases as the magnitude of the difference in crash rate to be detected as statistically significant decreases and also increases as the annual vehicle-miles of travel for the truck configurations of interest decrease.

Priority

Evaluations using the method previously outlined and of adequate scale to produce useful results will be expensive and time consuming. Moreover, experience shows that such research is high risk; that is, it has tended to produce unsatisfactory or inconclusive results because of the difficulty of data collection and the complexity of crash causation. Finally, the available evidence suggests that the influence of configuration on crash risk may be relatively small, compared with factors such as driver characteristics and supervision, road characteristics, and enforcement. The cost of such research might be more justifiable if the research were aimed at broader safety objectives than measurement of the safety effect of configuration alone.

SAFETY RESEARCH PROBLEM STATEMENT S.3

Develop and demonstrate a method to conduct comparative evaluations of safety performance of truck configurations using the case-control study design method.

Problem Statement

Same as for problem statement S.2.

Research Objective

Same as for problem statement S.2.

Possible Approaches

A case-control study of relative crash risk of alternative truck types would obtain information on all crashes of the vehicles of interest on a road system in a time period. Subsequently, at the site of each crash and typically at the same time of day and on the same day of the week, data would be collected on the characteristics of all trucks in the traffic stream. Comparison of the trucks in crashes (the cases) to the trucks in the traffic stream (the controls) would reveal characteristics that were over- or under-represented among the crash-involved trucks. For example, if a particular truck configuration made up a larger percentage of the crash-involved vehicles than of the control vehicles, this would indicate a higher crash risk for that configuration than for other types.

Observing the control vehicles at the same location and time of day as the crash eliminates these factors as confounding variables in the analysis. Certain variables of interest, including configuration and trailer body type, can be determined for the control vehicles by roadside observation of passing vehicles; other variables influencing risks (for example, driver characteristics) can only be obtained if control vehicles are stopped and inspected.

The case-control method has less demanding data requirements than the alternative method (described in problem statement S.2) of direct measurement of crash involvement rates from systemwide crash records of estimates of vehicle-miles of travel by truck type over a road system. The latter method requires detailed information on truck travel over the entire road system, classified by traffic, roadway, and truck characteristics. The case-control method produces estimates of relative risks rather than crash rates.

Data Requirements

Crash data would be collected specially for the study. The method would be the same as that for problem statement S.2. Control vehicle data would be collected by special vehicle counts conducted at the site of each crash, possibly supplemented by roadside inspections conducted by the police.

Present Status of Research

The method has been demonstrated in studies of truck crash risk by the Insurance Institute for Highway Safety (Stein and Jones 1988; Braver et al. 1997; Teoh et al. 2017).

Estimated Cost and Research Period

$400,000 to $750,000. Costs would depend on the objective of the research and especially on whether inspections of control vehicles would be required.

30 to 48 months. The 1997 and 2017 Insurance Institute for Highway Safety studies collected data for 17 months and 27 months respectively.

Priority

Considering cost, duration, and likelihood of success, case-control studies would be a more practical approach in the short term for improving quantitative understanding of the relationship of truck configuration to crash risk than the method outlined in problem statement S. 2.

SAFETY RESEARCH PROBLEM STATEMENT S.4

Develop and demonstrate a method to conduct comparative evaluations of the safety performance of truck configurations using trucking company data.

Problem Statement

Same as for problem statement S.2.

Research Objective

Same as for problem statement S.2.

Possible Approaches

Comparative evaluations using trucking company data can potentially provide accurate results because the truck configurations used and routes traveled by the trucks of a given company can be determined from truck dispatching data or from electronic data devices and telemetry systems on board a company's trucks. Crash data would be available from trucking company records and from crash reports submitted by the company to federal and state regulatory agencies. It should also be possible using trucking company data to document any differences in cargo types, weight distributions, and driver experience levels between the truck configurations of interest.

This type of evaluation is best suited to situations in which one or more trucking companies operate each of the truck configurations of interest. Studies that use trucking company data have a potential advantage over route- and network-based studies because exposure data can be drawn directly from a company's dispatching records. In the less-than-truckload (LTL) sector, companies often dispatch multiple trucks per day between specific terminal pairs, using a consistent route. In some cases, there may be LTL movements between a specific terminal pair each day, including truck movements by more than one truck configuration. The exposure for each truck would be almost perfectly matched because the same route would be used by each truck configuration. In the truckload (TL) sector, because movements are more likely to be directly from origin to destination rather than between terminals, statistical methods would be used to control for route characteristics in comparisons.

If such a study were conducted as a government initiative, the first step would be to define the objective, in terms of the configurations and operations to be compared, and the general method of the evaluation. Then trucking companies and industry associations would be recruited to participate. Participants would jointly decide on the data to be used. Data-sharing agreements governing data access and confidentiality would be established with trucking companies.

As an alternative, such a study could be industry led, with provisions for independent review of the data and analysis.

An evaluation that relied on company data would be challenging in several ways. Companies would be likely to agree to participate only if they were confident the results would be in their interests. Skepticism about the credibility of results would limit the value of the study in public debate over regulatory policy. Even if data and analysis were fully verified independently, the transferability of results to companies that did not participate would be uncertain.

An evaluation using trucking company data might be most feasible if it were part of a pilot trial of alternative configurations, as proposed in problem statement C.4. The opportunity to use the new truck type would be an incentive for participation, and the trial could be structured to facilitate safety comparisons. However, a large-scale trial (in terms of numbers of trucks, extent of routes, and duration) would be required to measure differences in safety performance unless the differences were pronounced.

Data Requirements

As previously described, the evaluation would employ company data on truck trip characteristics and truck crashes, conforming to an analysis plan agreed upon by the participants. Public records of crashes and inspections would provide a check on company data. A systematic data verification procedure would be required.

Present Status of Research

Glennon (1981) is an example of a comparative safety evaluation of alternative configurations (tractor-semitrailers and twin 28-ft. trailer combinations in LTL service), with an appropriate research design, conducted for a trucking company.

Road trials of alternative configurations in Europe (described in this committee's first report [TRB 2018, 13–14]) have included provisions for truck operators to provide company data to the public authority as part of the evaluation.

Estimated Cost and Research Period

In a government-led study, the cost to the government would be less than the cost of route- and network-based studies (see problem statement S.2) because the trucking companies would supply the data. The cost to the government for study design and organization, monitoring, and data management and analysis might be on the order of $350,000 to $450,000.

The duration would depend on the number of trucking companies and trucks participating and on the expected magnitudes of the safety performance differences to be measured. Probably at least 18 months of data collection would be required. Study organization, data collection, and analysis would then require 30 to 36 months.

Priority

The method could potentially produce the most accurate results of the three comparative evaluation methods outlined in these safety problem statements. However, because of the challenges previously noted, its practicality is difficult to assess. Government–industry discussions would be required to explore the feasibility of such research.

SAFETY RESEARCH PROBLEM STATEMENT S.5

Evaluate the potential safety performance of specific truck configurations using computer simulation modeling and test track evaluations.

Problem Statement

Comparative evaluations, as described in problem statements S.2, S.3, and S.4, can only be performed for truck configurations that are in use. To assess configurations not now in use but proposed for future use, the logical first step is computer simulation modeling of vehicle dynamics, supplemented with track testing.

Proposed configurations that perform well in simulation and track testing could then be evaluated in trial programs (as outlined in problem statement S.6). The most valuable comparative safety performance studies would measure the relationship between vehicle performance properties, as can be determined in simulation and track testing, and actual crash and casualty risk in use. The results of such research would validate the results of track testing and simulation as the basis for truck size and weight regulation and could guide the design of safer trucks, regardless of whether limits are changed.

Research Objective

The research would develop and demonstrate standard methods of computer simulation modeling and test track evaluation of vehicle dynamics for three applications: to assess the potential safety performance of proposed truck configurations before their operation on public highways is authorized, guide design of safer truck configurations, and provide the basis for performance-based regulation of size, weight, and other specifications of truck configurations.

Vehicle dynamic behavior also affects the interaction of the vehicle with the pavement and with bridges. This research could consider the advisability of coordinating simulation modeling for safety evaluation with modeling needs for evaluation of infrastructure impacts.

Possible Approaches

A research program to develop protocols for use of vehicle performance simulation modeling, track testing, and trials in evaluations of truck size and weight limits would define performance measures; identify appropriate models; define test procedures; determine the scale, participation requirements, and data collection and analysis methods of trials; design an administrative structure; and finally conduct selected evaluations as a demonstration of the procedures.

Past research has identified safety-related measures of truck performance that can be quantified for proposed new truck configurations and compared to the performance of existing truck configurations. These include, for example:

- Braking distance under specified conditions.
- Off-tracking in making turns under specified conditions.
- Rollover threshold.
- Load transfer ratio.

Proposed future trucks that demonstrate performance (as indicated by these measures) comparable to existing truck configurations that operate on U.S. highways are likely, if authorized in the future, to operate with crash rates and crash severity distributions similar to those for existing truck configurations. On the other hand, proposed future trucks that demonstrate performance (as indicated by one or more of these measures) that is poor in comparison to existing truck configurations may be less safe than existing truck configurations and thus may require more complete evaluation before being allowed to operate.

The primary application of track testing, which is much more expensive than computer simulation modeling, is to validate the results of simulation modeling.

Data Requirements

The measures to be quantified using vehicle dynamics simulation modeling and test track evaluation have been previously identified.

Present Status of Research

The evaluation of vehicle performance with simulation modeling for the USDOT 2016 truck size and weight study is an example of current capabilities (FHWA 2015d, 51–75, 193–232). Procedures used in countries that have adopted performance-based regulation are also relevant examples (for example, in Australia [(NTC 2008]).

Estimated Cost and Research Period

The cost of a study to develop and demonstrate a standard procedure for simulation and test track evaluation of vehicle handling and stability for the applications previously identified would be approximately $500,000 to $700,000. An estimated $1,000,000 to $3,000,000 over a 3-year period would be needed to conduct simulations and test-track evaluations for the various configurations that have been proposed recently by industry or considered in recent truck size and weight studies.

Priority

Vehicle dynamics simulation modeling, supplemented by test track evaluation as needed, should be a first step in assessing any truck configuration proposed for future operation on U.S. roads. Routine use of the method would be likely to lead to safety-enhancing design improvements for existing as well as new configurations.

SAFETY RESEARCH PROBLEM STATEMENT S.6

Develop a model to project the frequency of crashes on a road as a function of the vehicle mix and traffic volume on the road.

Problem Statement

The method commonly used in past truck size and weight studies to project the systemwide safety impact of a change in limits has been to assign each vehicle type a fixed crash involvement rate for each road functional class. The change in crash frequency would then be computed by multiplying the change in vehicle-miles of travel for each vehicle type and road class by the corresponding crash involvement rate and summing over all road classes. The TRB committee that reviewed the technical analyses of the 2016 USDOT study observed that this method is not a realistic representation of road safety (TRB 2015, 53–54). Changes in truck characteristics and truck traffic volume on a road resulting from a change in size and weight limits may change the crash involvement rates of all vehicles on the road. The change in truck traffic may affect the level of congestion or average speed on the road and may affect vehicle passing or other behaviors of automobile drivers on the road. As a result, the frequency of crashes not directly involving the new trucks could increase or decrease. Therefore, a more realistic model for projecting the safety impact of a change in size and weight limits would be one that predicts the frequency of crashes on a road as a function of traffic volume by vehicle type and other characteristics of the road, rather than a model of the crash rates of particular vehicle types.

Research Objective

The research would develop a model for projecting the change in the frequency of crashes and casualties on a road caused by a change in the traffic volume and mix of truck configuration types on the road.

Possible Approaches

Data sources would be the same as in problem statement S.2. Routes would be selected to provide a statistically valid sample of road and traffic conditions. The statistical analysis would estimate crash rates of road segments, rather than crash rates of vehicle types as in problem statement S.2.

Data Requirements

Same as in problem statement S.2.

Present Status of Research

The model of crash frequency on a road segment versus traffic volume that was explored in the USDOT 2016 Truck Size and Weight Study (FHWA 2015d, 21–23, 27–30) is an example of the basic approach of this research.

Jansen (1994) proposes alternative forms for a model relating the frequency of crashes on a road to traffic volume and vehicle mix.

A 1996 TRB committee report explained the rationale for the approach and reviewed earlier research (TRB 1996, 69–72).

Estimated Cost and Research Period

An exploratory data analysis to examine the feasibility and usefulness of this approach to modeling the safety impact of changes in truck size and weight limits could be conducted as an adjunct to the research outlined in problem statement S.2. The added cost, if the data were available from another study, would be approximately $150,000 to $200,000. The analysis could be conducted in 12 months, once the data were available.

Priority

This project would be basic research to improve understanding of how vehicle characteristics, traffic, and road characteristics affect safety, with potential application for evaluating truck size and weight limits and possibly also for evaluating other highway safety policies concerning enforcement, traffic management, and road design.

ENFORCEMENT RESEARCH

An evaluation of changes in truck size and weight limits must consider the interactions between regulations and size and weight limit enforcement. The characteristics of trucks on the road are determined by the combined influence of legal limits and enforcement effectiveness. A change in limits may change enforcement costs and effectiveness. Improvements in enforcement (through increased resources, stronger laws, better strategies, or automation) may mitigate the costs of truck traffic and the impacts of size and weight limit changes, but research on the frequency and cost of overloads and on enforcement effectiveness will be necessary to realize this benefit.

Overweight vehicles, including vehicles operating under permits and illegal overloads, account for a substantial and disproportionate share of traffic-related wear and deterioration of pavements (TRB 1990, 141; FHWA 2015c, 32) and of bridges (KLS and Wilbur Smith 2011, 17–33; Lou et al. 2016, 2017). Therefore, the impact of a change in regulations will depend on the effectiveness of enforcement of the new regulations and the effect of the change on the frequency of overweight vehicles. If a change in limits increases the frequency of damaging overloads (for example, by complicating enforcement or by leading to the adoption of vehicle configurations that are prone to overloading), this cost might negate any expected benefits of the change. If overloads are common enough on a road to be the dominant cause of pavement and bridge deterioration, then changing the nominal limits on the road might have little effect on costs.

The TRB Commercial Motor Vehicles committee found that data on frequency of overloads and understanding of enforcement effectiveness were inadequate to allow these effects of changes in limits to be evaluated (TRB 2002, 4–5, 170–175). This conclusion remains valid, despite advances in weight data collection. A further consequence of poor data on overweight vehicles is that it may bias models of the impacts of changing size and weight limits. If the truck traffic data used to calibrate the infrastructure and safety models used in a truck size and weight study underestimate the frequency of overweight vehicles, the models may overestimate the effects of changes in the limits.

The purposes of size and weight enforcement are to limit wear and damage to pavement and bridges and to avoid the safety hazard of illegal loads. Therefore, the ideal outcome measures for an enforcement program would be the effect of enforcement on infrastructure costs and safety. These ultimate outcomes can be estimated by measuring the impact of enforcement on the frequency and magnitudes of overloads.

To measure enforcement agency costs and identify possible effects of changes in limits on the costs, complexity, and feasibility of enforcement, a survey of enforcement agencies would be necessary. Data on the costs of discrete activities—for example, the costs of weighings, safety inspections of vehicles, and logbook inspections—would be most useful. A thorough understanding of enforcement costs and effectiveness would allow administrators to redirect resources to better meet the objectives of safety and control of infrastructure costs.

The potential of automated enforcement and other information technology applications to increase enforcement effectiveness should also be examined. Evaluation of these technologies should include the study of enforcement methods and legal provisions in countries that have changed their truck size and weight regulations to allow automated enforcement.

To fully evaluate alternative methods, research will be needed to design and conduct pilot studies evaluating strategies and technologies that point the way to more efficient and effective methods of attaining compliance with truck size and weight regulations.

The problem statements below outline four research projects:

E.1. Relationship between enforcement effort and compliance with size and weight laws.

E.2. Detailed accounting of U.S. truck size and weight enforcement costs.

E.3. Survey of truck size and weight enforcement in other countries.

E.4. Information technology applications to automate enforcement of weight and dimensional regulations.

These projects address enforcement of weight and dimensional regulations. Enforcement of safety standards (including requirements for drivers and equipment condition) is also relevant to truck size and weight regulation and could be improved through research and evaluation.

ENFORCEMENT RESEARCH PROBLEM STATEMENT E.1

Relationship between enforcement effort and compliance with size and weight laws.

Problem Statement

Projections of effects of changes in truck size and weight limits depend critically on assumptions about the effectiveness of enforcement of existing and proposed regulations. Moreover, effective enforcement could mitigate the costs of any change in size and weight regulations. However, no systematic nationwide information is available on enforcement effectiveness or on the relative effectiveness of alternative enforcement strategies or levels of effort.

Truck size and weight enforcement agencies have no reliable way to quantify the relationship of benefit to the costs of enforcement. As a result, it is difficult for the agencies to make decisions about the use of funds and human resources for the greatest effect.

Research Objective

This research would determine the relationship between the frequency of overloads on states' highways and characteristics of the states' truck weight enforcement programs, including level of effort, methods, and legal provisions.

The results would be applicable in assessing the impact of a change in size and weight regulations on enforcement cost and effectiveness and in coordinating size and weight regulations with enforcement practices. The results would also support more realistic projections of the effect of a change in limits on the axle load frequency distribution.

Finally, the results would allow truck size and weight enforcement agencies to more accurately predict the outcomes of resource investments and guide improvements in enforcement cost-effectiveness.

Possible Approaches

One possible method would be the following sequence of tasks:

1. Compile data showing frequency of loads exceeding axle and gross weight limits. Conduct of this research would require reliable weight data for a group of states by highway class, preferably for a period of years. The weight data may be the product of research under problem statement C.1. All states with usable weight data for at least one highway class (for example, rural Interstates) would be included in the study.
2. For each state for which the necessary weight data are available, assemble a profile of the state's truck weight enforcement level of effort (including funding, personnel, equipment, facilities, and numbers of weighings and inspections), enforcement methods, and legal provisions. Data sources would include the State Enforcement Plans submitted to meet FHWA requirements, other state records, and interviews with enforcement officials. The profile would include information on the use of relevant evidence laws and other legal tools for enforcement and on the state's overweight permitting practices, including permit fees and numbers of permits issued.
3. Assemble a profile of the industry composition of truck traffic on each state's roads: commodities carried, body types, and local and interstate shares of traffic. The 2002 Vehicle Inventory and Use Survey (VIUS), although outdated, may be the best available source. Weight

profiles on a highway depend on the industry composition of truck traffic, and overweight vehicles may be more common in certain industries.

4. Examine the enforcement characteristics and weight data to identify associations between measures of enforcement effort and frequency of overweight vehicles and axles. The analysis would take into account differences among the states in industry composition of truck traffic and in permitting practices. Statistical analysis will be used to identify correlations between effort and effectiveness. The analysis would also be qualitative, seeking similarities in the overall enforcement programs of states with relatively low frequencies of overloads. If historical data are available, the analysis will also examine whether changes over time in enforcement level of effort or methods lead to changes in the frequency of overloads.
5. Summarize the analysis with conclusions about the characteristics typical of effective enforcement programs and ineffective enforcement programs.
6. Based on the results, propose designs for controlled trials to test and confirm the relative effectiveness of alternative enforcement practices.

Data Requirements

As previously described, data requirements are data at the state level, or state and road class level, on (1) enforcement effectiveness as indicated by gross weight and axle weight data for the highway system, (2) characteristics of state enforcement programs, and (3) other characteristics of truck traffic related to truck weights (for example, industry composition).

Identification of states with the necessary weight data for the research and also analysis of the weight data would be conducted in conjunction with the research outlined in problem statement C.1 (development of truck traffic, weight, and configuration databases necessary for truck size and weight research).

Present Status of Research

The following are examples of relevant research:

- Fiorillo and Ghosn (2016): A study using a model of the relationship between enforcement effort and weight violations to design an optimum enforcement strategy within a budget.
- Strathman and Thiesen (2002): A trial of alternative enforcement strategies in Oregon.
- Taylor et al. (2000): Summary of results of studies in six states showing the effect of enforcement level of effort on the rate of weight violations and description of enforcement strategies demonstrated to be effective.
- Brown (2004): A general discussion of the potential of cost/benefit analysis to improve law enforcement and the difficulties of measuring inputs.

The enforcement and compliance literature review in the USDOT 2016 truck size and weight study cites other examples of the evaluation of enforcement effectiveness (FHWA 2015e, 106–141).

Estimated Cost and Research Period

$500,000 to 750,000
18 to 24 months (assuming that the necessary weight data are available from project C.1)

Priority

The research results would be useful in evaluations of truck size and weight limits because the impact of changes in limits will depend on the effectiveness of enforcement before and after the change. Changes in enforcement practices in coordination with changes in limits would be a means of mitigating the costs of the changes.

Research to understand the relationship between weight enforcement effort and the frequency of weight violations would be valuable in planning and budgeting enforcement programs, regardless of whether truck size and weight limits are changed.

ENFORCEMENT RESEARCH PROBLEM STATEMENT E.2

Detailed accounting of truck size and weight enforcement costs.

Problem Statement

Changes in truck size and weight regulations could affect the costs of enforcement. For example, the change might increase the duration or complexity of weighings and inspections or require new scale equipment. A regulatory change that involved a new permit system or special regulations for particular classes of vehicles could generate new enforcement costs. A change in cost could affect enforcement intensity and effectiveness. It is important to capture a baseline of costs of enforcement for the existing regulations to determine the change in cost from a change in regulations.

Research Objective

The objective of this research would be to create a method to project the cost of a change in the intensity or methods of a state truck weight enforcement program. The method could be used by enforcement administrators in planning and to support projections of potential enforcement cost impacts of changes in truck size and weight regulations.

Possible Approaches

Data on costs would be assembled from the State Enforcement Plan that each state submits to FHWA, supplemented by a survey of enforcement agencies. The plans provide aggregate information on funding, personnel, and equipment resources and enforcement activities. The survey would obtain more detailed data on unit costs of discrete enforcement activities, including costs of weighings and costs of vehicle safety and logbook inspections. The survey would also seek to resolve anomalies found in the states' enforcement plans cost data (as described in the USDOT 2016 enforcement cost study [FHWA 2015e, 44–49]). Finally, the survey would solicit inspection officials' opinions on possible enforcement cost impacts of specified hypothetical changes in size and weight regulations.

Based on the cost data, the investigators would develop an accounting model to estimate enforcement costs as a function of intensity and methods employed. Regression analysis of the relationship of costs to activities, across states or over time, could be used in developing cost factors. The investigators would also identify the cost elements that would be sensitive to changes in enforcement procedures necessitated by changes in size and weight regulations.

Data Requirements

State enforcement agencies already collect much of the data that the survey would request. It would be important for the investigators to clearly specify the data that they are seeking in the design of the survey instrument, but also to be prepared to assist agencies in completing the survey to ensure that the data are consistent and usable for research purposes.

Present Status of Research

The compliance analysis in the 2016 USDOT truck size and weight study illustrates the data available from the state enforcement plans, and the literature review describes other efforts to estimate costs (USDOT 2015e, 43–54, 110–112).

Estimated Cost and Research Period

$200,000 to $250,000
12 months

Priority

The USDOT 2016 study's enforcement cost analysis concluded that the impact on enforcement costs of the changes in limits considered in that study would be modest (FHWA 2015e, 57–58). The greater value of research on enforcement costs would be to give administrators a tool to benchmark their costs and expenditures against national averages and to support resource allocation decisions.

ENFORCEMENT RESEARCH PROBLEM STATEMENT E.3

Survey of truck size and weight enforcement and regulations in other countries.

Problem Statement

Several industrialized nations have enacted significant revisions in their motor vehicle size and weight regulations in recent decades. The revisions have been accompanied by adoption of new enforcement methods in several countries. The revised standards have been in effect for varying periods in countries of the European Union, Canada, Australia, New Zealand, and elsewhere. U.S. regulators should take advantage of this body of international experience when considering changes in U.S. regulations or improvements in enforcement methods.

Research Objective

The objective of the research would be to gather and synthesize information on practices and experiences of the surveyed countries regarding regulatory design and effects and the methods and intensity of enforcement effort necessary to ensure compliance.

Possible Approaches

The research would entail a survey with two components: a critical review of published documents of the national regulatory authorities and past surveys of international practice and interviews with regulatory officials in other countries. Areas of emphasis in the survey would include:

- Quantitative information on enforcement costs and expenditures and on measures of effectiveness.
- Specific information on enforcement techniques and strategies and on the legal basis of enforcement.
- Quantitative comparisons of the cost-effectiveness of alternative enforcement methods or levels of intensity.
- Specific information on the use of information technology in enforcement, including documentation of equipment and software used, data collected, data storage, and automated enforcement.
- Documentation of the applications of data in enforcement management and planning.

Data Requirements

As previously noted.

Present Status of Research

Various past surveys provide a starting point for research. For example, in Canada, Woodrooffe et al. (2010) and Moore et al. (2014), and in Europe, Honefanger et al. (2007). The USDOT 2016 study contains descriptions of regulatory practices in Canada, Europe, and Australia (FHWA 2015d, 138–150; FHWA 2015e, 142–147). National regulatory authorities publish summaries of their programs. For example, in Australia, NTC (2008) and National Heavy Vehicle Regulator (2018). Available documentation for the most part lacks quantitative information on costs and effectiveness.

Estimated Cost and Research Period

$150,000 to $250,000
15 to 24 months

Priority

A synthesis of experiences of nations that have changed truck size and weight regulations or enforcement methods in a transport environment comparable to the United States could provide valuable guidance for developing U.S. enforcement policies. Research has been performed, regulations implemented, and lessons learned. If the proposed research were successful, it could save money, time, and effort in planning regulatory reform in the United States.

ENFORCEMENT RESEARCH PROBLEM STATEMENT E.4

Design and conduct pilot studies to evaluate alternative methods of enforcing weight and dimension regulations, including information technology applications and automated enforcement.

Problem Statement

Effective enforcement of size and weight regulations is critical for controlling wear and damage to pavement and bridges and for reducing crash risk. The consequences of a change in truck size and weight regulations will depend strongly on the effectiveness of enforcement of both the prior limits and the new ones.

Enforcement agencies are responsible for designing strategies that make the best use of available resources for achieving enforcement objectives. Information technology provides opportunities to increase cost-effectiveness, but applications require development, testing, and demonstration. Automation of certain functions that support enforcement may improve enforcement of truck size and weight regulations as well as safety regulations by increasing the probability that enforcement officers detect violations and by allowing more efficient use of resources.

Research Objective

This research would compare the costs and effectiveness of alternative size and weight enforcement methods through full-scale trials of actual application of the methods, to aid enforcement agencies in managing their programs.

Possible Approaches

The federal government would recruit a small number of states (possibly three to six) to participate voluntarily in a program of testing and evaluating alternative enforcement methods. State laws governing enforcement would restrict the kinds of alternative methods that could be tested in certain states.

In partnership with state agencies, the investigators would select alternative methods appropriate for testing in each state. In each state, the investigators would plan and carry out experimental comparisons of the effectiveness of the selected alternatives. Experiments could take the form of side-by-side comparisons of alternatives in different districts or on different routes or before-and-after comparisons on selected routes.

The measure of effectiveness would be WIM records of vehicle and axle weight distributions on the roads within the test areas. Availability of weight data would be a factor in selecting states and designing the experiments. WIM measurements could be planned in conjunction with the research outlined in problem statement C.1. The trials would also record in detail the costs of the enforcement practices used in the trial. Statistical analysis would be used to estimate the effect of the alternative enforcement methods on the distributions of axle and gross weights in the test areas.

Data Requirements

As previously outlined, the requirements would be reliable weight and configuration data for the routes and periods of the trials and records of the costs of conducting the alternative enforcement activities.

Present Status of Research

The USDOT 2016 truck size and weight study conducted an extensive review of past research on the effectiveness of alternative enforcement methods (FHWA 2015e, 123–140).

The TRB Commercial Motor Vehicles committee (TRB 2002, 172–182) reviewed administrative and technological options for improving enforcement. The committee's list is still valid but would require updating.

Strathman and Thiesen (2002) report on a trial of alternative enforcement strategies in Oregon.

If the research outlined in problem statement E.3 were to be completed before this research, the results would provide examples of state-of-the-art methods in other countries.

Estimated Cost and Research Period

$800,000 to $1,200,000, plus in-kind contributions from participating states
Approximately 48 months:
- 18 to 24 months to organize and design trials
- 18 to 24 months for data collection
- 6 to 12 months for analysis and reporting

Priority

Enforcement pilot projects, either stand-alone or as part of a comprehensive evaluation of truck size and weight regulation, should be high priorities because of the importance of enforcement to controlling the costs of truck traffic. Developing and conducting pilots would be a relatively long-term effort. Enforcement pilot projects would be important part of a program of comprehensive regulatory reform, but would not be not essential in a more narrowly focused evaluation of changes in size and weight limits.

MODE AND VEHICLE CHOICE AND FREIGHT MARKET RESEARCH

Changes in truck size and weight regulations will change the truck configurations available to shippers and transportation companies and their relative costs. These firms will change their freight mode and vehicle choices in response. This response will determine the impacts of the regulatory change on pavements, bridges, safety, enforcement, shipper costs, and the location of economic activities. Therefore, credible projection of the impacts of changes in regulations requires the development of freight market models that predict mode and vehicle choices in response to changes in costs.

The key features of the most important modeling approaches are summarized in Table A.1. As

Table A.1 Summary of Features of Alternative Modeling Approaches

Features	**Econometric Models**		**Supply-Chain-Based Models**
	Discrete Choice Models	**Aggregate Market Share Models**	
Data needed for calibration	Disaggregate data with choices and attributes of modes/vehicles, shipments, and shippers	Market shares by commodity type and by attributes of vehicle/modes and shipments	No calibration needed
Data needed for application	Travel time and cost by mode and commodity type; sample of shipments	Travel time and cost by mode and commodity type	Disaggregate data about all components of transport and inventory costs, travel and cost by vehicles/modes, freight quantities by shipper and receiver
Output produced	Probability that an establishment selects a vehicle/mode	Market shares among modes/vehicles by commodity type	Choice of mode/vehicle and shipment size for an establishment and shipment
Ease of use, practicality	Once estimated, relatively easy to use and practical	Once estimated, relatively easy to use and practical	Easy to use
Quality of output	High	Low–medium	As high as the quality of the input data
Considers vehicle choice?	Yes	Yes	Yes
Suitability for policy applications	Best choice	Second-best choice	Not well suited

shown in the table, freight mode/vehicle choice models can be divided into two families: econometric and supply-chain-based models. The former use econometric techniques to capture the decision dynamics at the core of the freight mode/vehicle choice process, while the latter replicate the chain of decisions that minimizes logistical costs (transport plus inventory costs) by finding the mode/vehicle that provides the optimal combination of shipment size and frequency of delivery. Overall, econometric models provide the best trade-off between the ability to capture the decision dynamics that drive the choice of freight mode/vehicle and practicality, that is, the ability to use the models to predict the effects of alternative policy scenarios in real-life settings. Econometric models are divided into two subfamilies: discrete choice models (DCMs) and aggregate market share models.

Best Choice: Discrete Choice Models

DCMs try to capture the decision-making behavior of the agent in charge of making decisions on mode/vehicle choice, using random utility theory (Manski 1973, 1977). DCMs express the probability of choosing a mode/vehicle as a function of variables such as shipment size, cost and time for each mode/vehicle alternative, commodity type, and the attributes of the shipper. These utility functions, because of their empirical nature, capture the effects of the key independent variables, thus avoiding the need to collect highly detailed data about each variable that may influence freight mode/vehicle choices.

The data needed to estimate and use these modes are disaggregate, typically at the shipment level. The power of DCMs resides in their ability to consider the effect of spatial variables, for example, the distance between an establishment and the closest rail terminal or the effects of the frequency of rail service on the waiting times and ultimately the mode/vehicle decision. In doing so, it is important to properly consider the interplay between the choices of mode/vehicle and shipment size. Since carriers have to make deliveries within the constraints set by the customers, the decision made on shipment size and the carriers' mode/vehicle choices frequently boil down to selecting the alternative that provides the best match to the shipment size, as this would provide the fastest (the lowest need for delivery consolidation) and least expensive service.

A set of about 750 truck–rail DCMs was estimated as part of NCFRP Project 44, *Impacts of Policy-Induced Freight Modal Shifts* (Holguín-Veras et al., forthcoming), for key commodity types, using the U.S. Census Bureau's Commodity Flow Survey's (CFS's) confidential microdata. The CFS does not collect data about truck configuration types used; therefore, estimation of a vehicle choice model will require complementing the CFS data with vehicle choice data. This could be accomplished by adding questions about truck types for a subsample in the next CFS survey or by conducting a separate survey. A separate survey would be more practical in the short term, but estimating DCMs of freight mode/vehicle choice with the data from a single survey would eliminate concerns about data comparability that arise when different samples are used.

Second-Best Choice: Aggregate Market Share Models

Aggregate market share models express the market share of a mode/vehicle as a function of variables such as commodity type and the characteristics of the competing modes/vehicles (for example, time, cost). Aggregate models cannot consider the role played by attributes such as shipment size and other shipment-level or establishment-level factors that influence mode/vehicle choice and therefore are less sensitive to policy variables than DCMs.

Collecting the data needed to calibrate these models typically requires a large-scale freight survey. As part of NCFRP 44, a set of 266 aggregate market share models was estimated for dozens of commodity types. This was possible only because of access to the 2012 CFS data.

Supply-Chain-Based Models

These models attempt to replicate the process followed by private-sector companies when making mode/vehicle decisions. The models require estimates of the detailed cost components that make up logistics cost (the summation of transportation and inventory costs), as well as estimates of freight flows from each shipper to each customer. The most widely used model in this family is the Intermodal Transportation and Inventory Cost Model (ITIC) (FRA 2005, FHWA 2011).

The fundamental weakness of supply chain models such as the ITIC is the difficulty of collecting the data needed. The onerous cost of collecting the data needed is a consequence of the confidential nature of private-sector data and the heterogeneity of business conditions among industry sectors and companies. To cope with the lack of input data, model users sometimes have used aggregate freight flows and default values of the input data cost items. However, using average values of the numerous cost items that determine transportation and logistics costs does not provide much insight into mode/vehicle choice behavior. Deterministic supply chain models, even when implemented with disaggregate data as intended, are believed to exaggerate the sensitivity of mode choice to changes in the relative costs of modes (Abate et al. 2018).

Research Problems

A research program made up of the following projects would be consistent with previously stated considerations and would provide methods for USDOT to project freight market effects of changes in truck size and weight limits that would be useful for policy analysis:

- M.1 Adaptation and testing of freight mode choice models for application in truck size and weight limit policy studies.
- M.2 Development of a mode and vehicle choice model for application in truck size and weight limit policy studies.
- M.3 Development of a method of projecting railroad industry revenue impact, including revenue impacts for short-line railroads, of mode shifts caused by changes in truck size and weight limits.

MODE CHOICE RESEARCH PROBLEM STATEMENT M.1

Adaptation and testing of freight mode choice models for application in truck size and weight limit policy studies.

Problem Statement

Estimates of all categories of impact in prospective evaluations of changes in truck size and weight limits depend on projections of the changes in truck traffic that the change in limits will stimulate. The method of projecting freight mode shares in most past U.S. truck size and weight studies, which used a deterministic supply-chain-based model implemented with aggregate data, does not produce credible projections. Discrete choice models are the preferable method; such a model now under development may be applicable in evaluations of truck size and weight limits.

Research Objective

The research would evaluate and adapt models developed in past research to provide a freight mode choice model useful for projecting the effect of changes in truck size and weight limits on the distribution of freight among the truck, rail, and possibly barge modes.

Possible Approaches

The research could be carried out through the following tasks:

1. Adapt the truck–rail mode discrete choice model developed in NCFRP 44 (Holguín-Veras et al., forthcoming) for typical truck size and weight study applications and also for new applications, including projecting the effect of changes in truck user fees on mode choice.
2. Conduct trial model runs (for example, projecting mode shifts in the regulatory scenarios of the USDOT 2016 study) and compare quantitative results with results from alternative available models, including the ITIC and estimates of aggregate freight diversion derived by applying past studies' freight market elasticity estimates (for example, as reported in McCullough [2013] and Clark et al. [2005], and as applied in McCullough [2013, 10–12] and TRB [1990b, 82–83]).
3. From the results of the comparisons, determine the most credible available method of projecting modal diversion. The method may be a combination of models or a synthesis of results from more than one method. This task might be aided by convening a panel of freight market researchers and industry experts to review the model comparisons.
4. Apply sensitivity analysis to the results of recent truck size and weight studies (the 2016 or 2000 USDOT studies) to examine how the magnitude of modal diversion affects the net cost or benefit of changes in the regulations. This analysis is necessary to determine the priority that should be given to further development of freight market models for use in truck size and weight studies. If the sign of the net impact (that is, whether the net impact is positive or negative) is insensitive to the magnitude of the diversion, then simple methods of projecting market impacts will be adequate for policy analysis.
5. If the NCFRP model proves useful, update the model when new data from the 2017 CFS become available.
6. Prepare for longer term model improvements: (a) investigate methods of extending present models to include waterways transportation; (b) review the structure and data requirements of other countries' national freight market models (for example, de Jong and Baak 2016, Abate et al. 2018), and assess the applicability of similar approaches in the United States; (c) assess

the value and feasibility of augmenting or modifying future CFSs to improve data for freight market models.

Data Requirements

This research would test, adapt, and demonstrate applications of an existing model. Therefore, data requirements would not be extensive. If Task 5 were carried out, the data from the 2017 CFS would be required, together with updates of other data used in the NCFRP 44 models.

Present Status of Research

The models relevant for comparisons of methods and results are cited in the “Possible Approaches” section.

Estimated Cost and Research Period

16 to 24 months
$250,000 to $350,000

Priority

Because of the importance of projections of freight market response in evaluations of truck size and weight limits and the opportunity presented by newly developed models, this research merits high priority.

MODE CHOICE RESEARCH PROBLEM STATEMENT M.2

Development of a mode and vehicle choice model for application in truck size and weight limit policy studies.

Problem Statement

Changes in truck size and weight regulations may induce changes in shippers' choices of both mode and truck type: the nature and extent of these changes determine the infrastructure, safety, and other impacts of the regulatory change. The U.S. Census Bureau's CFS collects data on the mode of transport of sampled shipments (including for-hire truck, company-owned truck, railroad, and seven others) but not on other characteristics of trucks carrying the shipments. Therefore, it can provide insight to the impacts of changes in truck size and weight regulations on the choice of mode, but not on choice of truck configuration. Shortcomings of the methods of past truck size and weight studies for projecting mode and vehicle choice were previously described in this report. Therefore, a need exists to develop data and methods to project truck configuration choice that are consistent with the mode choice projection method that the research outlined in problem statement M.1 would provide.

Research Objective

This research would develop a DCM capable of projecting the effects of changes in truck size and weight regulations and of other policy changes on freight mode and vehicle choice, extending the capability of the mode choice model developed in the research outlined in problem statement M.1. If choice of shipment size were included, the form would be a discrete-continuous choice model. The model, in conjunction with historical data on weight distributions of truck configurations from research under problem statement C.1, should be capable of supporting projections of the change in truck axle and gross weight distributions resulting from a change in size and weight limits.

Possible Approaches

The research may be conducted through the following tasks:

1. Conduct qualitative research to identify relevant independent variables and to gain insight to assist in the design of the sampling plan and survey instrument.
2. Collect a sample of revealed preference or stated preference data to support model estimation.
3. Estimate the DCM or models, testing alternative specifications and functional forms.
4. Validate the results with a hold-out sample.
5. Demonstrate the use of the model for projecting mode and vehicle choice for regulatory scenarios, such as those in the 2016 or 2000 USDOT truck size and weight studies, and compare the results to the projections of the USDOT studies.
6. Demonstrate use of the model, together with historical data on weight distributions of truck configurations, for projecting the change in truck axle and gross weight distributions resulting from a change in size and weight limits.
7. Demonstrate use of the model to estimate the effect on mode choice of adjusting truck user fees or taxes to match highway infrastructure costs occasioned.
8. Specify methods for improving the model through expanded or more refined data collection, by means of modifications to future regular Census transportation surveys or ad hoc data collection.

The preferable modeling approach would be to estimate a single model in which each alternative truck configuration is treated as a mode along with rail, air, and water, using data from a single survey. This approach would require adding truck configuration questions to the CFS (or to a subsample of the CFS) or a new survey of shippers. A shipper survey of truck configuration choice would present difficulties. A shipper using its own truck fleet would know the configuration of the truck carrying its shipment, but a shipper using a for-hire motor carrier in general will not have a record of the configuration, and a for-hire motor carrier may consolidate shipments into other configurations after they leave shippers.

An alternative approach might be a modeling system that first projects mode choice (among truck, rail, and other) and then allocates truck shipments among configuration types by means of a stand-alone truck configuration choice model, possibly estimated using a new survey. Any such survey would be challenging, but possibly a small-scale survey would be practical and sufficient to at least test the approach.

A third approach to obtaining configuration choice data would be to survey truck operators rather than shippers. This was the approach of the Brookings Institution study *Road Work*, which estimated a model of a truck operator's configuration choice as a function of commodity carried, capacities and configurations of alternative vehicles, vehicle operating and capital costs, length of haul, and state size and weight restrictions. The model was estimated with disaggregate data from the Census Bureau's Truck Inventory and Use Survey, supplemented with vehicle capital and operating cost data from other sources (Small et al. 1989, 44–52). Truck operators would be expected to have more accurate information about truck configuration than would shippers. The research could explore this method by reestimating the *Road Work* model with data from the most recent (2002) Vehicle Inventory and Use Survey.

Shipper preference for a truck configuration that is not now in use cannot be directly observed. A model could project use of such vehicles by including vehicle performance characteristics (for example, capacity, maneuverability, route restrictions, operating and capital costs) as independent variables.

Data Requirements

The principal requirement is survey data reporting shippers' or carriers' choices of truck configuration for freight transportation, together with information on the characteristics of the cargos, origins, and destinations. Also required will be data on travel times for alternative configurations for origin–destination pairs, capacities and other characteristics of the alternative configurations, and freight rates or vehicle operating and capital costs.

Present Status of Research

The following are examples of data sources used in studies of freight truck configuration choice:

- A trip survey of truck drivers (Holguín-Veras 2002).
- Truck operator 1-week trip logs required by the government of Denmark for a sample of drivers (Abate and de Jong 2014).
- The Truck Inventory and Use Survey (Small et al. 1989).

Estimated Cost and Research Period

The cost will depend primarily on the method and scale of data collection on truck configuration choice. For a study that includes a pilot survey of shippers or pilot operators:

30 to 36 months
$1,000,000 to $1,200,000

Priority

An improved method of projecting the effect of changes in size and weight limits on mode and vehicle choice would enhance the credibility and usefulness of projections, in a comprehensive truck size and weight study, of all other effects of changes in the limits. In addition, an improved method would be useful for evaluating changes in user fees and other policies to mitigate truck costs and improve freight transportation efficiency, regardless of whether truck size and weight limits are changed.

Results of past studies suggest that changes in the trucks used to carry freight that are already on the highways will be more significant than the change in the quantity of freight carried by trucks for determining the costs and benefits of the changes in truck size and weight limits that are most commonly considered. Therefore, the vehicle choice component of the freight market model used in truck size and weight evaluations merits at least as much attention as the truck/rail mode choice component.

MODE CHOICE RESEARCH PROBLEM STATEMENT M.3

Development of a method of projecting railroad industry revenue impact, including revenue impacts for short-line railroads, of mode shifts caused by changes in truck size and weight limits.

Problem Statement

Past federal truck size and weight studies have considered the effects of changing size and weight limits on railroad industry revenue and profits among the impacts considered to be significant for assessing policy alternatives. The financial projections depend on mode share projections, which were questionable in past studies (as explained in the discussion of supply-chain based models in the introduction to the mode choice problem statements above). In addition, rail industry representatives expressed to the committee their skepticism about the realism of the financial projections. Finally, past studies did not have a method suitable for projecting financial impacts for short-line or regional railroads.

Research Objective

This research will assess whether improved projections of freight mode shifts caused by changes in size and weight limits will lead to more credible estimates of railroad industry revenue impact, compare alternative modeling approaches to projecting revenue impact, develop a method to project revenue impact for short-line railroads, and propose a method for conducting rail industry financial analysis in future truck size and weight studies.

Possible Approaches

The research could be conducted through the following tasks:

1. Estimate rail price response and change in revenue from a change in size and weight limits through use of a simple method: using mode shift estimates from the model of M.1 and applying price elasticity estimates from the literature to estimate the implied price response and consequent revenue loss. A range of estimates would be produced, reflecting the uncertainties in the inputs to the calculation.
2. Compare estimates to the results of USDOT's Integrated Financial Model, which was used to project rail financial impacts in the 2016 and 2000 USDOT truck size and weight studies. The research would also identify any alternative practical financial models available and include those in the comparisons.
3. Assess the effects of size and weight limit changes on the traffic and revenue of short-line railroads by individually analyzing a sample of short lines. The analysis would be based on projections of freight diversion using the model developed under problem statement M.1 combined with qualitative assessments of modal competition in the local and regional markets of the sample short lines.
4. Assess results of the alternative modeling approaches with the aid of an expert panel that includes freight industry executives and academic experts in these industries.
5. Identify and assess alternative qualitative and quantitative approaches to projecting the long-term implications of the projected revenue changes on railroad industry costs, profits, scale, and investment.
6. Based on the results of the previously outlined tasks, identify a practical and credible method for projecting rail industry financial impacts in future truck size and weight limit evaluations.

Data Requirements

This exploratory research would primarily rely on data and results from past studies, including the research outlined in problem statement M.1. The short-line revenue impact analysis would require the compilation of local freight market data for the sample short lines. Publicly available data may be sufficient, but access to proprietary data, with appropriate confidentiality agreements with voluntarily participating short lines, might be useful in some cases.

Present Status of Research

The USDOT Integrated Financial Model is described in FHWA (2015a), pp. 230–235.

Models for predicting the effect of competition on railroad rates have been developed by Christensen Associates (2009, 11-1–11-30) and by Wilson and Wolak (2015). The models are to be used to assess the effect of competition from other railroads and from waterways and cannot be applied directly to estimate effects of a change in truck costs. However, the methods and data sources of the models may suggest methods of analyzing rail revenue effects of increased truck competition.

Estimated Cost and Research Period

$200,000 to $450,000
12 to 24 months
Costs and duration will depend on the scope of data collection for the estimation of short line financial impacts.

Priority

Assessment of potential rail industry impacts has always been necessary in federal truck size and weight studies and has been a factor in legislative decisions on the regulations. These impacts are relevant particularly to the extent that highway user fees and taxes paid by freight-carrying trucks are not commensurate with the cost of providing highway facilities for them. Therefore, careful and defensible estimates would have value.

CROSS-CUTTING TOPICS: EVALUATION OF REGULATORY OPTIONS

The problem statements presented in this section are for research on topics other than the development of specific impact models to support evaluation of truck size and weight regulations. The first topic is to provide the truck traffic data needed for projections of all categories of impacts. The remaining three topics concern the methods of conducting truck size and weight policy studies: evaluation of provisions of truck size and weight regulations other than dimensional limits, analysis of the consequences of coordination of size and weight regulations with other road management policies, and development of methods for pilot evaluations of alternative vehicles.

The problem statements are for the following projects:

C.1 Develop truck traffic, weight, and configuration databases necessary for truck size and weight research and evaluations.

C.2 Develop methods for incorporating common features of regulatory schemes in evaluations of costs and benefits of changing truck size and weight limits.

C.3. Develop an analysis framework for evaluating the potential of the coordination of size and weight regulations with other road management policies (user fees, enforcement of regulations, road and bridge design, asset management) to increase public benefits from the road system.

C.4. Develop protocols for conducting staged pilot evaluations of truck configurations.

CROSS-CUTTING TOPICS RESEARCH PROBLEM STATEMENT C.1

Develop truck traffic, weight, and configuration databases necessary for truck size and weight research and evaluations.

Problem Statement

Data on combination vehicle and heavy single-unit truck traffic volume and axle weight spectra by configuration type are necessary for the research on infrastructure, safety, and freight market impacts outlined in the previous sections. Truck traffic estimates are needed for specific bridges and road segments chosen as sample elements for evaluation of bridge and pavement impacts and for estimation of crash rates. Baseline estimates of truck traffic volumes by weight and configuration for the entire highway system are necessary to project changes in truck traffic caused by changes in size and weight limits. Systemwide baseline and projected traffic estimates are necessary to produce systemwide estimates of bridge, pavement, and safety impacts of changing the limits.

Research Objective

The objective of the research is to produce the required traffic estimates for the truck size and weight research program through a central analysis activity, in close coordination with the research on each of the impact categories, to ensure consistency and avoid duplication of effort.

Possible Approaches

The project could proceed in the following steps:

1. Identify the truck traffic data requirements of the pavement, bridge, crash rate, and mode shift research projects.
2. Identify the state WIM and automatic vehicle classification sites in the FHWA Vehicle Travel Information System (VTRIS) (FHWA 2017b) that can provide data for these applications.
3. Apply established editing and filtering techniques to the data from these sites to produce observations suitable for modeling purposes.
4. Provide datasets to the researchers conducting the pavement, bridge, and safety projects that contain the traffic and weight data required for these projects.
5. Develop and apply methods for scaling observations from the nonrandom and geographically sparse collection of WIM sites to estimates of truck traffic volumes, axle load distributions, and gross weight distributions by configuration for the United States and for individual states by road system.

Developing useful weight data for local roads will be a major challenge. The research would include assessing the feasibility of estimating local road weight distributions with available data. Some states may report data from sites on minor arterial roads to FHWA, but VTRIS may contain little or no data for lower functional classes. A survey of the states might identify sources of weight data from portable WIM equipment or data collected by county or local governments that are not now being collated or reported to FHWA. It may be necessary to extend the scope of the research to include the design and conduct of a pilot effort to collect WIM data on local roads, following a statistical sampling design.

Data Requirements

Data would come primarily from the weight and vehicle classification data reported by the states to FHWA and entered in the VTRIS system, supplemented with weight data collected by the FHWA Long-Term

Pavement Performance (LTPP) Program. A revision of VTRIS is in progress in 2018. The consistency of state reporting of weight data to FHWA is unknown. To produce the weight database, an outreach effort may be necessary to upgrade the rate and reliability of state reporting.

Present Status of Research

The experience of the USDOT 2016 study in developing traffic and load spectra for the study's infrastructure and safety evaluations provides a starting point for this project (FHWA 2016c, 21–30). The methods for producing estimates of truck traffic on the nationwide road network for FHWA's Freight Analysis Framework may also be applicable.

Al-Qadi et al. (2017) provide an example of editing WIM data for application in pavement and bridge research and an example of a method of scaling WIM observations to traffic estimates on the links of the statewide road system. Walker and Cebon (2011) describe the process of producing research quality data from WIM observations for the LTPP Program. Sivakumar et al. (2011) describe WIM data requirements for bridge analysis.

Estimated Cost and Research Period

14 to 22 months
$600,000 to $850,000

Early completion would facilitate other research in the roadmap.

If the research were extended to include new data collection on local roads, cost and duration would be greater.

Priority

The traffic estimates are essential for research on pavement, bridge, and safety impacts of changes in truck size and weight limits.

The data and methods developed in the research would have general value for freight planning at the state and national levels and in state asset management programs.

CROSS-CUTTING TOPICS RESEARCH PROBLEM STATEMENT C.2

Develop methods for incorporating common features of regulatory schemes in evaluations of the costs and benefits of changing truck size and weight limits.

Problem Statement

The 2016 USDOT truck size and weight study defined each of the scenarios evaluated in terms of a single specified truck configuration and the road network on which the truck was assumed to operate. In earlier truck size and weight studies (including the 1990 and 2002 TRB studies and the 1981 and 2000 USDOT studies), the scenarios evaluated were regulatory schemes defined by size and weight limits (that is, maximum allowable axle and vehicle weights and vehicle and trailer lengths) and trailer configurations allowed, together with rules such as road network restrictions, permit requirements for vehicles exceeding certain limits, performance standards for vehicle stability and control, user fees related to infrastructure costs imposed by particular truck operations, grandfather or other special exemptions from limits, and specification of federal regulations as either preemptive (overriding conflicting state regulations) or permissive (allowing states to choose whether to adopt new limits). Estimates of costs and benefits will depend on these features of the regulations.

Restrictions supplementing the size and weight limits have been used or proposed as a means to reduce the infrastructure costs and crash risks of new vehicles. For example, route restrictions are intended to keep vehicles off minor roads that may have incompatible geometry and vulnerable bridges.

Research is needed to guide the design of supplemental restrictions that are effective at mitigating costs and to assess the effect of such restrictions on truck operators' decisions to adopt the new vehicles.

In addition, research is needed to develop a method of predicting the specifications (trailer configurations, axle spacing, weights) of the new vehicles that truck operators would adopt in response to changes in maximum weight and length limits. The research outlined in problem statement M.2 on truck operators' equipment selection decisions would address this question.

Research Objective

The research would develop methods to evaluate supplemental restrictions on the use of new vehicles, including route restrictions, bridge postings (blocking new vehicles from using certain bridges that are open to vehicles meeting the present size and weight limits), and adjustments in truck user fees and taxes to match the infrastructure costs occasioned. The methods would provide estimates of the effectiveness of the restrictions in mitigating the costs of operating the new vehicles and the effect of the restrictions on the volume of use of the new vehicles.

Possible Approaches

Evaluation of route restrictions would include analysis of the historical performance of the route restrictions now in federal and state law, including provisions in federal law that restrict certain vehicles to the federally designated National Network and access routes (where state law does not otherwise allow the vehicles) and state laws that allow operation of larger combination vehicles on specified routes. The research would assess the effectiveness of enforcement of the route restrictions, changes in the extent of the restrictions over time, and the effectiveness of the restrictions in preserving infrastructure on minor roads and directing truck traffic to relatively low risk roads.

It may be possible to quantitatively estimate the effects of route restrictions and bridge postings on the use of new vehicles with the model of freight mode and vehicle choice developed in the research outlined in problem statement M.1. In a simulation using the mode/vehicle choice model, imposition of a route restriction could be represented as an added dollar cost, added truck length of haul, and/or added truck travel time.

Evaluation of the effect of bridge postings would begin by selecting a sample of the bridges that would be posted on account of the new trucks (according to the bridge impacts analysis in a truck size and weight limits study) and obtaining data of truck traffic volume on the bridges, to determine the share of all truck traffic potentially affected by the postings. Then in a simulation of mode/vehicle choice, the detour required for the new trucks to avoid the posted bridges could be represented as an added dollar cost of choosing the new truck.

More realistic estimates of the effects of route restrictions and bridge postings could be obtained with a high geographic resolution network model of freight traffic flows. No existing network model is sufficiently detailed for this application. Developing such a model would be a long-term and expensive undertaking.

The effects of changes in truck user fees and taxes (including fuel taxes, registration fees, federal use tax and excise taxes, and tolls) on the use of new vehicles could be estimated with the freight mode and vehicle choice model developed in the research outlined in problem statement M.2.

Data Requirements

Evaluation of route restrictions will require data identifying the roads on which specific truck types are allowed and prohibited today, nationwide or in selected states. The evaluation will also require truck volume, weight, and classification data to assess compliance with the restrictions. Truck traffic data on minor roads is necessary to assess enforcement effectiveness and may require special data collection.

Present Status of Research

The TRB committee studies on twin trailer trucks (TRB 1986), the Turner proposal (TRB 1990b), and access routes for large trucks (TRB 1989) applied simple assumptions to estimate the effect of route restrictions on the use and impacts of larger trucks.

Estimated Cost and Research Period

For a project to develop methods for evaluating route restrictions, bridge postings, and adjustments in truck user fees and taxes:

20 to 24 months
$350,000 to $400,000

Evaluations of additional kinds of restrictions (for example, vehicle performance standards, permissive versus preemptive federal regulations) would require greater resources.

Priority

Methods to assess supplemental restrictions will be necessary in any future comprehensive truck size and weight study. Projections of the effects of such rules would be very approximate, to be verified by monitoring after enactment of any changes in regulations.

Route restrictions, bridge postings, and special user fees and taxes are a part of truck regulation today; therefore, research to evaluate such provisions could reveal opportunities to reduce the costs of truck operations regardless of whether size and weight limits are changed.

CROSS-CUTTING TOPICS RESEARCH PROBLEM STATEMENT C.3

Develop an analysis framework for evaluating the potential to coordinate size and weight regulations with other road management policies (user fees, enforcement of regulations, road and bridge design, and asset management) to increase public benefits from the road system.

Problem Statement

The TRB Commercial Motor Vehicles committee concluded that:

> Changes in truck size and weight regulations made in coordination with complementary changes in the management of the highway system offer the greatest potential to improve the functioning of the system. The best way to control the costs of accommodating existing and future truck traffic is by coordinating practices in all areas of highway management: design and maintenance of pavement and bridges; highway user regulations, including vehicle and driver regulations related to safety; and highway user fees (TRB 2002, 3).
>
> The most useful size and weight study would be a structured search for better means of attaining these goals [greater benefit and reduced costs from truck traffic]. These means might entail changes in size and weight regulations coordinated with changes in safety regulations, highway design, user fees, or other areas of highway management (TRB 2002, 41–42).

Past USDOT truck size and weight studies recognized the value of policy coordination. The Secretary of Transportation's transmittal letter to Congress that accompanied the USDOT 1981 truck size and weight study stated that "size and weight legislation should be developed in concert with user charge legislation" and that the department would present "a coordinated position on both issues" based on the results of the truck size and weight study and the USDOT highway cost allocation study that was underway at the same time (Lewis 1981).

Coordinated practices are equally desirable with regard to regulation and infrastructure standards. The 1964 federal truck size and weight study was motivated by recognition of the need to coordinate highway design standards with truck size and weight regulation (DOC 1964, 16–17), at a time when the results of the American Association of State Highway Officials (AASHO) Road Test had become available and construction of the Interstate system was still at an early stage. The 1968 federal study (USDOT 1968) focused on determining optimum weight limits, considering the trade-off between reduced truck transport cost and increased infrastructure costs. The Canadian Vehicle Weights and Dimensions study (RTAC 1986) is an example of an evaluation of the coordination of truck size and weight limits with safety regulation, through the mechanism of performance-based standards.

Although the potential value of coordinating highway management policies has been recognized, studies that attempted to design and evaluate practical policies have been rare. Research is needed to develop a methodology for such evaluations.

Research Objective

The objective is to develop and demonstrate an analysis framework that FHWA or other highway agencies can apply to identify coordinated policies that increase public benefits of the highway freight transportation system. The analysis framework is the logical structure of a truck size and weight study, that is, definition of the objectives of regulatory changes, identification of policy options to be evaluated, and definition of the criteria for comparing the options.

Possible Approaches

The tasks in the research would be as follows:

1. Identify options (in addition to size and weight limits) for controlling the costs of truck traffic, including actions that specifically target any cost increases expected from changes in truck size and weight limits. Past studies have identified important options, which include:

    - Vehicle performance standards to regulate the handling and stability of larger vehicles.
    - Adjustments in user fees to fully recover the costs of bridge and pavement wear caused by trucks.
    - Enhanced enforcement to reduce the frequency of illegal loads.
    - Route restrictions that limit larger vehicles to routes where their use would have relatively high benefits and relatively low added infrastructure cost.
    - Improvements in bridge management systems to provide information about actual bridge structural capacity.

2. Develop and demonstrate methods for simulating the effects of each option on truck traffic and costs, using existing models and models developed in other research outlined in this roadmap. The freight mode/vehicle choice model developed in project M.1 would be applicable to projecting effects of changes in user fees. The results of project E.1 would indicate the potential benefit of improved weight enforcement. The results of the bridge research projects B.1 and B.3 may indicate a method of estimating the potential gain in bridge system reliability from more rigorous bridge management practices that lead to more cost-effective maintenance, rehabilitation, posting, and permit vehicle routing decisions (Moses 2001, 4–5).
3. Develop and demonstrate a procedure for conducting a truck size and weight study structured to design a package of policies aimed at attaining a target level of improvement in the truck freight transportation system. For example, the target could be defined in terms of attaining a target percentage of savings in shipper costs plus infrastructure costs of truck freight, with the constraints that impact on safety be neutral or positive and that any added highway agency costs be covered by adjustments in truck user fees. Alternative packages of policies would be evaluated and compared using the methods developed in Task 2.

Data Requirements

This research would require no data beyond those required in the research projects in the roadmap to develop the necessary models.

Present Status of Research

The following are examples of studies that considered the benefits of coordinating highway management policies:

- The TRB committee study of the Turner Proposal (TRB 1990b) is an example of a truck size and weight study that sought changes in size and weight limits and other practices to attain a defined performance objective, the simultaneous reduction of shippers’ freight costs and infrastructure costs, although the study did not identify such a win-win outcome.
- The 1981 and 2000 USDOT truck size and weight studies (USDOT 1981, USDOT 2000a) were conducted in conjunction with highway cost allocation studies, in recognition of the relationship between size and weight limits and cost-based user fees, although they did not

estimate how changes in user fees would affect the outcome of changes in size and weight limits.

- The Brookings Institution study *Road Work* (Small et al. 1989), is an example of a policy evaluation with a defined objective, optimization of user fees and pavement design. The study presented evidence that setting truck user fees equal to the cost of road wear caused by each truck, together with adoption of pavement designs that minimized life-cycle costs, would incentivize truck operators to adopt truck configurations that reduced pavement wear and would substantially improve highway freight transportation efficiency, considering highway agency costs and shipper costs.

Estimated Cost and Research Period

A research team with expertise in both economic and engineering models would be needed.
Assuming the necessary models (as previously outlined in the possible approach) are available, the research could be conducted with 20 person-months of effort, in a period of 20 months, at a cost of $400,000.

Priority

Past research suggests that coordination of size and weight regulation with user fee, infrastructure, and safety regulatory policies could yield important public benefits. Therefore, research to identify and assess practical forms of coordination could have high value.

CROSS-CUTTING TOPICS RESEARCH PROBLEM STATEMENT C.4

Develop protocols for conducting staged road trials of truck configurations.

Problem Statement

Projections of the outcomes of regulatory changes based on historical experience cannot be highly reliable, even if models are greatly refined, because of the complexity of the highway freight transportation system. Vehicle simulation modeling, track testing, full-scale road trials of vehicles in commercial operation, and systematic permanent monitoring of truck traffic and truck-related costs are methods to provide information for more credible evaluations of truck regulations.

Research Objective

This research would define performance measures to be monitored, develop data collection and analysis methods, determine participation rules, and develop an administrative structure for conducting road trials of alternative truck configurations in commercial use. The research would then conduct small-scale trials to demonstrate the method.

Possible Approaches

Road trials would be conducted with the voluntary participation of state governments and selected motor carriers. Carriers would adopt the configurations to be evaluated in their regular operations. Use of the new configurations might be restricted to certain routes in the participating states.

A trial would be designed as a controlled experiment, beginning with specific, quantitative definitions of the impacts to be observed and development of a detailed data collection and analysis plan.

The structure of a trial could be staged; that is, it would start with a small number of vehicles and carriers. Experience in the first stage would guide a decision on whether to expand the trial to more carriers and vehicles or to extend its duration.

The impacts observed in the trials could include carrier acceptance and use of new configurations, enforcement agencies' experiences with the new configurations, traffic interaction, and crash characteristics. Differences in crash involvement rate among configuration types could be measured conclusively only in a trial involving large numbers of trucks or of long duration. Observation of effects on pavement might be possible in a large-scale, long-duration trial. Effect on bridge durability probably would not be observable in a trial of practical scale. Information relevant to infrastructure impact (for example, dynamic effects) might be obtainable through instrumentation of pavements and bridges.

Data Requirements

Most data on truck use, crashes, infrastructure response, traffic interaction, and enforcement experience would be collected specially for the trial. Carriers, as a condition of participation, could be required to provide data, with appropriate confidentiality protections, on use, costs, and safety experiences.

Present Status of Research

The committee's first report describes pilot evaluations of trucks in other countries (TRB 2018, 13–14). In the United States, FHWA, at the direction of Congress, conducted monitoring and evaluation of the impacts of the 100,000 lb. gross weight trucks that Congress allowed to operate on interstate highways in

Maine and Vermont (FHWA 2012a, 2012b). The FHWA reports contain conclusions about pavement and bridge impacts, but observe that the duration of the pilot was too short to evaluate long-term industry response or safety consequences. The effect of truck traffic weights and volumes on local roads was measured, but impacts on local bridges were not evaluated.

The TRB *Commercial Vehicles* committee report proposed experimental design requirements, including sample size requirements, and administrative arrangements, including measures to assure safety, for road trials of the consequences of changes in truck size and weight regulations. (TRB 2002, 125–130, 200–203).

Estimated Cost and Research Period

The cost of a trial program would depend on the number of trucking companies and the number of trucks participating in the trial. A typical trial might operate for 3 years, but evaluation results might be available sooner if a large number of trucks participated. The estimated cost is $1,000,000 to $3,000,000, depending on the duration of the study.

Priority

A trial program may be the best method for verifying the findings of computer simulation modeling and test track evaluations. A road trial could also provide information to check predictions of infrastructure and enforcement impacts and carrier acceptance of alternative configurations. Studies of this type should be assigned a high priority, as a trial program may be a better method for accommodating new truck configurations on the road network than simply permitting the new truck configurations to operate nationwide.

APPENDIX B

WEBINAR PARTICIPANTS

Public Webinar, November 17, 2017
Views of U.S. Department of Transportation experts on research needs and current research activities related to the effects of truck traffic on bridges and pavements

Panel (all Federal Highway Administration, U.S. Department of Transportation):
- Derek Constable
- Lubin Gao
- Joey Hartmann
- Steven Jessberger
- Tom Kearney
- Jean Nehme
- Tom Yu

Public Webinar, January 29, 2018
Research priorities for improving understanding of the effects of truck traffic on bridges and pavements

Panel on bridge research priorities:
- Bert Hartman, Oregon Department of Transportation
- Michael Johnson, California Department of Transportation
- Steve Lauer, Wiss, Janney, Elstner Associates, Inc.
- Hani Nassif, Rutgers University

Panel on pavement research priorities:
- Bouzid Choubane, Florida Department of Transportation
- Shongtao Dai, Minnesota Department of Transportation
- Lev Khazanovich, University of Pittsburgh
- Dallas Little, Texas A&M University
- Mark Snyder, Pavement Engineering and Research Consultants, LLC

Public Webinar, February 8, 2018
Research priorities for improving understanding of the effects of changes in truck size and weight limits on traffic safety and on enforcement of truck regulations

Panel:
- Linda Boyle, University of Washington
- Paul Jovanis, The Pennsylvania State University
- Jonathan Regehr, University of Manitoba
- Eric Teoh, Insurance Institute for Highway Safety
- John Woodrooffe, University of Michigan Transportation Research Institute

Public Webinar, April 2, 2018
Research priorities for improving understanding of the effects of changes in truck size and weight limits on freight shipper and carrier mode choice and truck configuration choice, highway freight volume, and shipper freight costs

Panel:

Megersa Abera Abate, World Bank
Chris Caplice, Massachusetts Institute of Technology
Kalin Pacheco, California Department of Transportation
Birat Pandey, Federal Highway Administration

STUDY COMMITTEE BIOGRAPHICAL INFORMATION

James Winebrake (*Chair*) is Professor and Dean of the College of Liberal Arts at the Rochester Institute of Technology (RIT) and Co-Director of the RIT Laboratory for Environmental Computing and Decision Making. Previously, he was the chair of the Department of Science, Technology, and Society/Public Policy, and directed a BS program in public policy and an MS program in science, technology, and public policy. Dr. Winebrake has published on a wide variety of transportation, energy, and environmental topics. Over the past decade, he has been involved in evaluating the environmental impacts of freight transportation, with emphasis on air quality, health, climate change, and regulations. He was chair of the 2013–2015 TRB Committee for Review of the U.S. Department of Transportation (USDOT) Truck Size and Weight Study. Before joining RIT, Dr. Winebrake served as an Associate Professor of integrated science and technology at James Madison University. He received a BS in physics from Lafayette College, an MS in technology and policy from the Massachusetts Institute of Technology, and a PhD in energy management and policy from the University of Pennsylvania.

Imad L. Al-Qadi is the Bliss Professor of Engineering, Director of the Advanced Transportation Research and Engineering Laboratory, and founding Director of the Illinois Center for Transportation at the University of Illinois at Urbana-Champaign. Before that, he was the Charles E. Via, Jr., Professor at Virginia Tech. His work has resulted in the development of new pavement modeling methods, techniques, and testing standards. He is the past President of the American Society of Civil Engineers' (ASCE's) Transportation and Development Institute Board of Governors and is the Editor-in-Chief of the *International Journal of Pavement Engineering*. Professor Al-Qadi has received the National Science Foundation's Young Investigator Award, the quadrennial International Geosynthetics Society Award, the ASCE James Laurel Prize, the American Road and Transportation Builders Association Steinberg Award, the ASCE Turner Award, and the French Limoges Medal. In 2010 he was elected as an ASCE Distinguished Member. He is a registered professional engineer. Professor Al-Qadi edited 20 proceedings and authored or coauthored more than 600 publications. Professor Al-Qadi holds a BS from Yarmouk University and an MEng and a PhD from The Pennsylvania State University, all in civil engineering.

Gongkang Fu is a Professor of civil and architectural engineering at the Illinois Institute of Technology. His research concerns bridge design methods, methods for evaluating bridge capacity, bridge inspection and monitoring techniques, bridge load rating and overweight truck permits, engineering management, uncertainty modeling and analysis, and system reliability assessment. He was the head of structures research with the New York State Department of Transportation for 7 years, and has worked on design and research projects for various agencies, including the Federal Highway Administration, National Cooperative Highway Research Program, National Science Foundation, and the Arizona, California, Georgia, Illinois, Michigan, New York, and Ohio departments of transportation. He is a registered Professional Engineer in Michigan and New York. He received a PhD in civil engineering from Case Western Reserve University and an MS in engineering mechanics and a BS in civil engineering from Tongji University, Shanghai, China.

David L. Harkey is the President of the Insurance Institute for Highway Safety and Highway Loss Data Institute. His research focuses on applying transportation engineering principles and research evaluation methodologies to improve highway safety for motorists, pedestrians, and bicyclists in the areas of traffic operations, geometric design, and roadside design. Until 2017, he was the Director of the Highway Safety Research Center at the University of North Carolina, where he collaborated with behavioral researchers on studies to develop countermeasures that combine engineering and behavioral components to address safety problems. Dr. Harkey is the chair of TRB's Safety and Systems Users Group. He is a registered professional engineer in North Carolina and holds a PhD in civil engineering from North Carolina State University and an MSE and a BSCE from the University of North Carolina at Charlotte.

Douglas W. Harwood is a Program Director at the Transportation Research Center at MRIGlobal, a not-for-profit research institute located in Kansas City, Missouri. Mr. Harwood has more than 40 years of research experience with federal, state, and local agencies. His research is in the areas of traffic safety, highway geometric design, and traffic operations. He has led research projects that have addressed the relationship of vehicle characteristics to highway geometric design and traffic safety. Mr. Harwood is a licensed professional engineer in Kansas, Missouri, and Montana. He is a member of TRB's Committee on Highway Safety Performance and holds a BS in civil engineering from Clarkson College and an MS in transportation engineering from Purdue University.

Susan E. Hida is the Assistant State Bridge Engineer for the California Department of Transportation (Caltrans) in Sacramento. Her professional experience includes the design and analysis of bridges, as well as structural reliability and probability-based design methods. She is a former member of the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures and chaired the AASHTO Loads/Load Distribution Technical Committee. Previously, she was the Chair of the Caltrans Loads Committee and Project Engineer for the Bayshore Viaduct Seismic Retrofit, Grass Valley–Yuba City Seismic Retrofit, and New River Bridge redesign, among others. Ms. Hida is a licensed professional engineer in California and Oregon. She received the James E. Roberts Award for Outstanding Structures Engineering in Transportation. She holds a BS and an MS in civil engineering (structural emphasis) from Purdue University and an MS in civil engineering (emphasis on structural mechanics) from Princeton University.

José Holguín-Veras is the William H. Hart Professor and Director of the Volvo Research and Educational Foundations Center of Excellence for Sustainable Urban Freight Systems and the Center for Infrastructure, Transportation, and the Environment at Rensselaer Polytechnic Institute. His research interests are in the areas of freight transportation modeling and economics and humanitarian logistics. His work has opened the door to new paradigms for freight systems that increase economic efficiency as well as environmental justice. His work on humanitarian logistics has played an influential role in disaster response procedures and has led to deeper insight into how to best respond to large disasters and catastrophic events. He is the President of the Scientific Committee of the Pan-American Conferences of Traffic and Transportation Engineering and a member of the Scientific Committee of the World Conference of Transport Research. He is a member of numerous technical committees and editorial boards of leading journals. He is the recipient of numerous awards, including the 2013 White House's Transportation Champion of Change Award, the 1996 Milton Pikarsky Memorial Award, and the 2001 National Science Foundation's CAREER Award. He received a BSC from the Universidad Autónoma de Santo Domingo in 1982, an MSC from the Universidad Central de Venezuela in 1984, and a PhD from The University of Texas at Austin.

Clinton V. Oster, Jr., is Professor Emeritus and former Associate Dean for Bloomington Programs at the School of Public and Environmental Affairs at Indiana University. His research has centered on aviation safety, airline economics and competition policy, energy policy, and environmental and natural resource policy. He has coauthored five books on various aspects of air transportation, including *Deregulation and the Future of Intercity Passenger Travel* with John Meyer and *Managing the Skies: Public Policy, Organization, and Financing of Air Navigation* with John Strong. He has chaired and served on numerous National Research Council committees, including the Committee for the Study of Traffic Safety Lessons from Benchmark Nations, Committee on the Federal Employers' Liability Act, Committee on the Effects of Commuting on Pilot Fatigue, and Committee on the National Aeronautics and Space Administration's ' National Aviation Operational Monitoring Service Project. He was a member of the Committee for Guidance on Setting and Enforcing Speed Limits and the Committee for a Study on Air Passenger Service and Safety Since Deregulation. He holds a BS in engineering from Princeton University, an MS in public affairs from Carnegie Mellon University, and a PhD in economics from Harvard University.

Michael Tooley is the Director of the Montana Department of Transportation, a position that he has held since January 2013. Before that, he served in the Montana Highway Patrol for 28 years, including 4 years as a colonel. He has extensive experience in highway safety project management and research. He has a BS in public safety administration from Grand Canyon University and he has attended the Federal Bureau of Investigation National Academy at the University of Virginia and the Senior Executives in State and Local Government program at Harvard University's John F. Kennedy School of Government.

Dennis F. Wilkie (NAE) retired as Corporate Vice President and Chief of Staff for the Integrated Electronic Systems Sector at Motorola, Inc., in 2002. He joined Motorola, Inc., in 1996 after retiring from the Ford Motor Company. During his years at Motorola he was involved in automotive electronic systems, energy systems, and embedded electronic control systems management. He retired from the Ford Motor Company in 1996 as Corporate Vice President for Business Development. He worked at Ford for 28 years, and his work involved the application of control theory and systems engineering to automobiles and the field of transportation. He worked on automotive electronic systems issues as well as infrastructure issues such as automated highways, automated transportation systems, and intelligent transportation systems. In recent years, he has focused on the use of electronics and wireless technology to bring new levels of convenience, safety, and information to vehicles. He was elected to the National Academy of Engineering in 2000 and is a Fellow of the Society of Automotive Engineers. He holds a BS and an MS in electrical engineering from Wayne State University, a PhD in electrical engineering from the University of Illinois, and an MS in management (Sloan Fellow) from the Massachusetts Institute of Technology.

Sharon L. Wood (NAE) is the Dean of the Cockrell School of Engineering and a professor in the Department of Civil, Architectural and Environmental Engineering at the University of Texas at Austin. She holds the Cockrell Family Chair in Engineering No. 14. Her research interests include developing passive sensors to monitor the condition of civil infrastructure systems, investigating the fatigue response of cable-stayed and prestressed concrete bridges, and improving the seismic response of reinforced concrete buildings. She was elected to the National Academy of Engineering in 2013. Professor Wood is a past President of the American Concrete Institute and a member of its Structural Concrete Building Code Committee. She holds a BS in civil engineering from the University of Virginia and an MS and a PhD in civil engineering from the University of Illinois at Urbana-Champaign.