Large-Truck Safety Research

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ABSTRACT

Federal truck size and weight limits have existed since 1956. Their original intent was to protect the federal investment in the Interstate system. These limits were maximum allowable limits. Minor changes were made to these limits, but they remained maximum allowable. The Surface Transportation Assistance Act (STAA) of 1982 changed all that. Federal limits became mandatory minimums and for the first time vehicle length was included. The establishment of a national truck network was also included in the 1982 STAA. To clearly understand the problems facing the highway community in implementing the truck size and weight provisions of the 1982 STAA, it is necessary to fully understand those provisions. In this paper a history of the federal size and weight limits is presented, the new limits are explained, and some of the critical issues that have surfaced during implementation of these provisions are described.

In 1975 a new research project was initiated in the federally coordinated program of highway research and development in response to a need for better information concerning the safety implications of increased truck size and weight limits. This project was designated Project 1U, "Safety Aspects of Increased Size and Weight of Heavy Vehicles." In recent years this project has been expanded to include more general truck safety issues, and the title has been changed to "Large Truck Safety Research."

BACKGROUND

The trucking industry has experienced phenomenal growth in the last several decades; there have been significant increases in the volume of trucks, especially large combinations, on many highways. Trucks now represent more than 20 percent of the vehicles on some major arterials. The average size of trucks has gradually increased over the years, and twin-trailer combinations have become common in many western states. As the volumes of large commercial motor vehicles have grown, public concern about the safety of those vehicles has also increased. Not only are large combinations perceived as having poor handling and performance characteristics, but there is also concern about the increasing discrepancy between the size of trucks and passenger vehicles that are sharing the same roadway.

Federal and state regulations have generally limited increases in the sizes and weights of commercial motor vehicles. All states regulate truck dimensions such as length, width, axle weights, and gross vehicle weight, and federal statutes required states to restrict vehicle width, axle weight and spacing, and gross vehicle weight on the Interstate system.

The original federal limits were established in the Federal-Aid Highway Act of 1956, the same act that authorized the first expenditures for the Interstate highway system. Those limits were intended to protect the federal investment in the Interstate system. In 1974, in response to the oil embargo, Congress increased the federal weight limits, which permitted states to increase their weight limits on the Interstate system from 18,000 to 20,000 lb for single axles, from 32,000 to 34,000 lb for tandem axles, and from 73,280 to 80,000 lb gross vehicle weight.

Sweeping changes to truck size and weight limits were made in the Surface Transportation Assistance Act (STAA) of 1982. First, federal gross vehicle weight limits and axle weight limits on the Interstate system were made minimum as well as maximum to compel the three "barrier" states along the Mississippi River to raise their weight limits on the Interstate system to the federal maximum. Second, federal requirements concerning vehicle lengths were established for the first time. States were required to permit combinations with two 28-ft trailing units and combinations with a single 48-ft semitrailer on Interstate and designated Federal-Aid primary highways, and they were prohibited from imposing overall length limits for semitrailer and double-bottom combinations on those highways. Third, the 1982 STAA increased the maximum width of trucks that states were required to permit on Interstate and designated primary highways from 96 to 102 in.

Implementing the vehicle length and width provisions of the 1982 STAA was difficult. One reason for this difficulty was that the only criteria specified by Congress for designating highways were that segments be safe for the larger vehicles and that the segments form a "national network," which implies a considerable degree of route continuity. There was little firm evidence, however, to determine what highway design characteristics would be unsafe for vehicles with the dimensions specified by the STAA.

Sections 138 and 415 of the 1982 STAA, which called for a study of the feasibility of allowing truck combinations up to 110 ft in length to operate on a limited system of highways, also required an analysis of the safety of large trucks on various highway types. In the limited time available for that study, little original research could be conducted on access needs, equipment requirements, driver qualifications, operational restrictions, and other factors that affect the safe operation of longer combinations. Potential safety impacts could only be discussed in general terms on the basis of the limited research that had been done by states that currently permit the operation of turnpike doubles, Rocky-Mountain doubles, and triples. Much more research is required on the operational and safety problems of longer combinations.

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PROJECT DESCRIPTION

The original objective of Project 1U was to determine the impact of increases in truck size and weight limits on highway safety and to develop cost-effective solutions to identified safety problems. In recent years the objective has been expanded to include the identification of truck safety problems related to highway design or operation and the development of countermeasures.

The project can be divided into four basic areas of research, generally referred to as tasks. The first task, "Accident Investigation of Large Trucks," includes all the studies in the project involving accident and exposure data collection analysis. The second task, "Effect of Large Trucks on Safety of Traffic Operations," includes studies that involve the interaction of trucks with various highway design elements, such as grades, interchanges, two-lane roads, and intersections. The third task, "The Effect of Truck Size on the Interaction of Trucks with Other Vehicles," involves the investigation of the effect of trucks on other vehicles. Research on automobile driver behavior as well as splash and spray is included in this task. The fourth task, "Safety Impact of Large Truck Dynamics," focuses on vehicle handling. It includes the development and use of vehicle simulation models as well as full-scale testing of large trucks.

PAST AND ONGOING RESEARCH

The first study conducted in Project 1U was the most ambitious, the most controversial, and has drawn the most attention since its inception in 1975. The contract was titled, "The Effect of Truck Size and Weight on Accident Experience and Traffic Operations," but it has been commonly referred to as the BioTech study because it was conducted by BioTechnology, Inc. (1,2). This contract was, in reality, two separate studies that were awarded as one contract. It is the first portion of the contract, which deals with truck accidents, that has drawn all the attention.

Effects of Trucks on Accidents

This study attempted to address the basic question of how various truck characteristics (especially truck size and weight variables) influence truck accident experience. To accomplish this, an ambitious data collection scheme was developed. Six states were selected partly on the basis of the range of truck types common to those states. Individual roadway segments were then selected in each state to represent various roadway types and characteristics.

For 1 1/2 years, detailed accident data were collected for each large truck accident at each site. These data included detailed descriptions of the trucks, roadways, drivers, environmental conditions, and accidents. At the same time, detailed classification data were being collected using automated cameras and surveys at truck scales. These data were used to calculate vehicle miles of travel by truck and driver characteristics.

These data were then used to calculate accident rates that could be compared to determine the influence of various factors on truck accident experience. The two primary issues that were to be addressed in this study, vehicle weight and truck type, resulted in the two most interesting and controversial results of the study. The truck type analysis concluded that twin-trailer combinations, or doubles, experienced higher accident rates than did tractor-semitrailer combinations, or singles. The truck weight analysis concluded that increased truck weight did not increase truck accident rates. The analysis of truck weight data indicated that empty combinations experienced much higher accident rates than loaded trucks.

These two conclusions were quite controversial. Reviews of the report by representatives of the trucking industry pointed out many errors in the report and in the way the study was conducted. They generally dismissed the report's conclusions as inaccurate or unsubstantiated. A later, much more extensive review pointed out many problems with the way data were collected and analyzed. Although the impact of these various criticisms on the accuracy of the study conclusions has never been determined, they have severely reduced the credibility of this study.

Effects of Trucks on Traffic Operations

The second portion of this contract dealt with the effect of truck size and weight on traffic operations. A number of geometric conditions were selected under which it was hypothesized that larger or heavier trucks might influence traffic operations. The selected geometries were upgrades (short, long, slight, steep), downgrades (long, steep), curves (freeway, nonfreeway), grade-curve combinations, merge areas, ramps, and urban intersections. Matched weight and operational data were gathered at these sites on nearly 6,000 trucks ranging in gross weight from approximately 20,000 to 160,000 lb. Operational measures including volumes, speeds, and vehicle headways were obtained for many different traffic conditions and roadway geometries by using electronic roadway sensors. From these data, accident potential, vehicle delay, and passing behavior were analyzed for the various roadway conditions.

Three general issues were examined: (a) whether trucks with different loads or configurations have different impacts on traffic operations; (b) whether there are correlations among truck characteristics and traffic speed, headway, and other measures of traffic operations; and (c) whether the effect of truck weight on speed can be predicted. Among the findings of the study were that (a) loaded vehicles and doubles traveled slower, deviated more from the average speed of other traffic, and caused following vehicles to decelerate faster and leave shorter headways on upgrades than empty trucks and singles, respectively; (b) truck length does not have a significant effect on traffic operations; (c) the most serious safety problems caused by large trucks are on upgrades; and (d) statistically, only about one-third of the effects of trucks on traffic operations could be explained by differences in truck size and weight for the range of sizes and weights tested.

Information About Trucks and Automobile Drivers

Many motorists experience anxiety when driving near large commercial motor vehicles. The FHWA was concerned that such anxieties might influence the driving performance and behavior of some motorists and actually create unsafe driving situations. In other words, the truck would contribute to accidents just by being there; the automobile drivers, while passing, merging, or otherwise interacting with these large trucks, might behave in an unsafe manner because of concern about a big truck.

Two studies were initiated to examine this issue. One specifically addressed the influence of truck size on driver behavior; the second examined driver attitudes toward larger trucks.

The first study, titled "The Effect of Truck Size on Driver Behavior," was conducted by the Institute for Research (3). As part of this study, several specific automobile-truck interaction situations were selected for study. Specifically, the influence of truck length and configuration was examined at a freeway entrance merge, a main-line lane change, and a narrow bridge. Truck width was studied in a rural two-lane, two-way passing situation. The influence of length and configuration was also examined in a two-lane, two-way passing situation, but problems were experienced with data collection during this experiment and no results were obtained. Field work involved the collection of microscopic traffic measures using the Traffic Evaluator System, photographic data, and observations of erratic maneuvers and vehicle types. In general, the study did not indicate any serious driver behavioral problems associated with the presence of large trucks.

One experiment consisted of operating a wide truck on a narrow two-lane road to determine the behavior of automobile drivers in passing situations. In general, automobile drivers did adjust their driving behavior as trucks got wider, but not in an unsafe manner. Lateral placement, gap acceptance, and following distance all changed but within reasonable levels.

Another experiment examined the effect of truck length on the merging and weaving behavior of automobile drivers. To quote the authors of the report (3,p.14):

> While there were more forced lane changes, gore encroachments, and braking near the triple trailer combinations in the merging situation and more lane changes in front of the triple in a weaving situation, it is possible that these effects were due to lower speeds of the triple, which was interjected into the traffic stream for study purposes; hence, the effect may have been due to vehicle speed rather than configuration.
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> Thus, there was no basis for an indictment of increased truck length regarding the safety of nearby vehicles. On the other hand the weaknesses in the data precluded any strong conclusions regarding the absence of deleterious effects.

The companion study, entitled "Motorists' Attitudes Towards Large Trucks," was intended to survey driver attitudes to determine whether certain truck configurations create high levels of anxiety or concern in specific driving situations. Administrative problems, however, prevented the study from being completed.

Braking and Handling Characteristics of Heavy Trucks

One hypothesis concerning larger and heavier trucks was that increases in size and weight would adversely affect the braking and handling properties of these vehicles. Several studies were initiated simultaneously to begin to address this issue.

The purpose of the first study was to develop or modify a vehicle simulation model to analyze the braking and handling ability of large trucks. In this study, the Highway Safety Research Institute (HSRI), now known as the University of Michigan Transportation Research Institute (UMTRI), modified their handling and performance model to allow analyses of multitrailer combinations and to meet other FHWA specifications. The second study was simply an effort to make several full-scale tests of large trucks to validate the model described. This study was conducted by the Texas Transportation Institute. The third study involved the development and fabrication of an instrumentation package to be used in later full-scale truck-handling tests. This contract was conducted by Systems Technology, Inc.

None of these studies resulted in any actual examinations of vehicle handling. All three studies were aimed at developing useful tools for vehicle-handling research. As such, they served as a lead-in to a major truck-handling study conducted by UMTRI as part of Project 1U. The final report of that study, titled "Influence of Size and Weight Variables on the Stability and Control Properties of Heavy Trucks," is being prepared for publication (4).

As the title indicates, this study examined how variations in truck size and weight influenced the braking and handling ability of large trucks. The study included both vehicle simulations and full-scale testing. Six general issues were addressed in the final report: axle weights, gross vehicle weight, length of individual units or overall vehicles, types of multitrailer combinations, vehicle width, and bridge formula constraints.

The conclusions are too extensive to list here but two conclusions are especially worthy of discussion because of their timeliness and the interest generated by them. The first involves various multitrailer combinations and a phenomenon known as "rearward amplification." This is a characteristic of multiunit vehicles in which the lateral acceleration experienced by the first unit in a quick evasive maneuver is amplified rearward to such an extent that the rearmost unit could be caused to roll over.

A comparison of various truck configurations determined that western twin-trailer combinations and triple-trailer combinations exhibited the highest amplification ratios (lateral acceleration of the rearmost trailer/lateral acceleration of the tractor) with the triple experiencing an amplification ratio of 3 to 1. Other research conducted by UMTRI for Canada indicates that improved coupling mechanisms could reduce these amplification ratios and reduce the opportunity for rear-trailer rollover accidents.

A second important conclusion of the study about vehicle width was that increasing truck widths from 96 to 102 in. might be one of the most important improvements to vehicle dynamics possible. Widening tractor-semitrailer combinations could result in improvements in rollover thresholds of up to 18 percent (if both the tractor and trailer are widened). To realize the full improvement in stability, however, a 102-in-wide trailing unit must be equipped with wider axles than are used on a 96-in-wide unit. The wider tire and spring spacings significantly improve the rollover threshold.

Cargo Shifting in Trucks

There was one contract let to study vehicle handling in Project 1U entitled "Simulation of Cargo Shifting Effects on Vehicle Handling," which was conducted by the Applied Physics Laboratory. This study (5) attempted to model the dynamics of trucks with shifting cargoes such as tankers and trucks with hanging sides of meat. The final model developed could predict the influences of liquid sloshing with some success but could not predict the influence of swinging meat. Fortunately, from a vehicle dynamics point of view, the meat industry appears to be reducing the amount of beef and pork that is shipped in sides. Most meat leaves slaughterhouses boxed in smaller portions, which eliminates this problem.

Truck Splash and Spray

Another study in Project 1U addressed an issue that has concerned the public for many years--truck splash and spray. There was some fear that longer trucks, especially multitrailer combinations, would create more splash and spray than conventional combinations.

The study, which was conducted by Systems Technology, Inc., examined the influence of truck size and weight on splash and spray and tested possible solutions to the splash and spray problem (6). The study involved wind tunnel tests and extensive controlled field tests. The study concluded that larger trucks did not create significantly greater spray patterns primarily because as trailers are added to a combination, the wheel paths of the last trailer are virtually dry. The major part of the spray for any combination is generated by the tractor so little water is left for the trailer wheels. The field tests of countermeasures resulted in several promising prototype solutions and one quite effective off-the-shelf device. That type of device, which might be generically called a fuzzy mud flap, is now being marketed by several companies and is the basis of the recent legislation requiring splash and spray suppression devices on trucks.

As stated earlier, the initial intent of Project 1U was to examine the safety consequences of increased truck size and weight and to develop possible countermeasures. As the project plan was being developed and input was being solicited from FHWA operating offices and the states, it became apparent that there were a number of general truck safety issues, not related to truck size and weight, that were of concern to the highway community. When these were determined to be related to the design or operation of the highway, they were included in the project. To understand the full scope of the project, it is important to be familiar with these studies.

Runaway Trucks on Steep Downgrades

A longstanding safety concern for both truckers and the highway community is the problem of runaway trucks on steep downgrades. Several years ago the American Trucking Association suggested that a method be developed to help drivers anticipate the severity of downgrades so that they could adjust their approach speeds accordingly. Systems Technology, Inc. (STI), conducted a study to determine the feasibility of a grade severity rating system (7).

This method originally consisted of a numerical rating scheme for downgrades that would be based on their overall severity measured by truck brake temperatures. This concept proved to be unfeasible for trucks of various weights. Furthermore, although it would provide better information to the truck driver concerning the relative severity of the grade, it also presumed that the driver would know what to do with that information.

To resolve these two problems, a second study was awarded to STI to develop a system that would provide maximum safe speeds of descent based on the severity of the grade and the weight of the truck (8). This proved to be a feasible concept. The result was a system of weight-specific speed signs that are currently being field tested in several states by the Transportation Research Corporation.

Truck Stopping Sight Distance

Another issue of less apparent importance, but certainly a nagging issue of concern to the highway community, is the subject of truck stopping sight distance requirements. Present crest vertical curves have been designed to provide adequate stopping distance for typical automobiles. Trucks have always been ignored, on the assumption that the superior sight distance that large trucks provide their drivers more than compensates for the inferior braking ability of these vehicles. This assumption had never been adequately addressed, however, so a contract was awarded to Automated Sciences Group, Inc., to examine truck stopping sight distance requirements and to quantify any apparent deficiencies (9). The study consisted of an analysis of typical truck configurations on various combinations of grades. The study concluded that truck stopping sight distance is not adequate on a large number of crest vertical curves but that, on the majority of these hills, deficiencies occur on only a small portion of the curve. Few grade combinations produce a situation in which truck sight distance is overly restricted for any significant portion of the grade.

Offtracking

One performance characteristic of large trucks that has concerned highway engineers over the years has been offtracking. Design engineers use turning templates to determine the ability of trucks to negotiate a specific turn. Unfortunately, the existing templates are limited in terms of curve radii and truck configuration, and cumbersome and time-consuming procedures have been required to generate new templates. To correct these problems, a user-friendly offtracking program has been developed that operates on an Apple II computer. With this program, the user may specify the path and configuration of a truck and the program will generate a turning template for use in highway design. Currently, work is under way to develop an IBM-PC version of this program with increased capability. The new version will also provide digital output for users without an x-y plotter.

Currently, there are a number of truck safety research studies under way and several are planned for the near future. These studies involve improved accident and exposure data, truck-related operational problems, and future truck issues.

CURRENT STUDIES

Impact of Specific Geometric Features on Truck Operations and Safety at Interchanges

The BioTech study examined, among other things, accident location. Freeway off-ramps surfaced as a high accident location for trucks. For this reason a study was initiated to examine the causes of truck accidents at interchange off-ramps and to develop possible countermeasures. This study, which is nearing completion, is being conducted by UMTRI. Off-ramps with a history of truck accidents have been identified using state accident records; and descriptive data on the sites have been obtained from the state or through site visits. A vehicle dynamics model was used to assess the design adequacy of the ramps in question and to identify possible solutions.

Truck Tractive Power Criteria

One long-recognized performance problem that trucks exhibit on highways is their inability to maintain acceptable operating speeds on long upgrades. Present day highway design procedures provide guidance for determining the performance of a typical truck on the grade in question. Unfortunately, this information is based on data collected nearly 30 years ago. Since that time, several factors have influenced truck power and performance requirements. Among those factors have been the heavier average loads that truck tractors have been required to pull, improved highways that allow higher operating speeds, and concerns for improving fuel efficiency. These factors have led to many changes in vehicle design and equipment, especially in the last 10 years. Some changes, such as improved aerodynamic design, affect vehicle performance without changing the weight-to-horsepower ratio. Because the effect of these many changes on hill-climbing performance is uncertain, a study has been initiated to determine the present performance of trucks on grades and to develop an improved procedure for highway designers to use in predicting truck performance. The study, being conducted by UMTRI, will consist of extensive field data collection and model development. A simplified procedure using charts or graphs plus a predictive model with the capability of predicting the performance of any specific truck will be developed as end products.

Development of a Large-Truck Safety Data Needs Study Plan

Recent studies, both under Project 1U and under other sponsorship, have indicated that a comprehensive large-truck accident study is needed. A study was recently begun to identify and rank the most critical issues that must be addressed in a major truck accident study and to develop a data collection and analysis plan for such a study.

Techniques for Improving the Dynamic Ability of Multitrailer Combination Vehicles

As mentioned earlier, multitrailer combinations exhibit certain undesirable dynamic properties that could result in vehicle rollovers under some conditions. Improved dollies and coupling devices appear to enhance the dynamic properties of such combinations. This is important in light of the expected expansion of doubles operations nationwide and the proposal to allow longer combinations nationwide.

A study is under way to determine the desirable properties of trailer coupling mechanisms using vehicle simulation, develop a prototype dolly incorporating these features, and test the full-scale prototype dolly as well as various on-the-market dollies. These dollies will be tested for both dynamic improvement and operational ease.

Operation of Larger Trucks on Roads and Streets with Restrictive Geometry

Some states have expressed concerns about operational and safety problems of STAA vehicles on roadways with narrow lanes and shoulders, sharp curves, and other substandard design features. For instance, the offtracking of a tractor-48-ft-semitrailer combination might cause operational and safety problems on some tight mountain curves. A study is under way to identify the types of geometric deficiencies that cause the greatest problems for long, wide combinations. Different vehicle configurations will be run over test segments to examine the operational and safety problems of each type of vehicle for different traffic and roadway design situations. The study will attempt to determine the geometric and traffic conditions under which various vehicles become unsafe.

Safety Criteria for a Multitrailer Truck Highway Network

The limited information available on the operation of very long combination trucks on turnpikes and western highways indicates that these vehicles have a good safety record. It is generally assumed that this is due in large part to the restrictive controls and special permits under which these vehicles operate. In this study, the cost-effectiveness of various controls on the vehicle, driver, and general operation of longer combinations will be examined to determine which controls may be most desirable in different situations.

PLANNED RESEARCH

Effectiveness of Truck Roadway and Lane Restrictions

Background

An informal telephone survey conducted in 1980 revealed that at least eight state transportation agencies have enacted traffic regulations that restrict trucks from certain lanes on multilane highways. Some regulations absolutely prohibit trucks from the median lane or restrict them to only the rightmost two lanes. Others allow brief travel in the restricted lanes for passing. In several states, the truck restriction applies to all freeways statewide; in others, it is in effect only on specific facilities. Reasons for prohibiting trucks from one or more lanes include reducing congestion and delay, increasing capacity, and reducing stress and intimidation in passenger automobile drivers.

The present scarcity of funding for major transportation improvements and the persistently high cost of energy suggest a continued trend toward smaller, more fuel-efficient passenger vehicles and, at the same time, larger, higher capacity trucks. Both use existing transportation facilities that, of necessity, must accommodate all types of motor vehicle traffic for many years to come. Partial segregation of the largest and smallest vehicles through the application of restrictive traffic regulations may be effective in reducing congestion, delay, and driver stress on freeways. On the other hand, there may be significant operational problems associated with restrictions of this type: Are entrance and exit maneuvers hampered by the concentration of trucks in the rightmost lanes? Is the level of compliance unacceptable? Is adequate enforcement impractical?

Objective

The experiences of those states (or other transportation authorities) who have enacted truck restrictions have not been collectively studied and documented. A comprehensive investigation of the various regulations and their effects on highway operations and safety would provide a valuable reference for transportation officials considering such options.

Aspects of the truck restrictions that should be studied include

- The basis for each restriction;
- Definition of vehicles subject to restrictions;
- Methods of conveying restrictions to drivers;
- Methods and levels of enforcement;
- Levels of compliance;
- Effects on operations (speed, lane-volume distribution, interchange operation, etc.); and

- Effects on safety (accidents, driver stress, etc.).

Safety Implications of Future Configurations

Background

In the past changes in truck size and weight limits sometimes resulted in unexpected truck configurations with less than desirable performance characteristics or other problems. Changes to existing limits in the near future could create similar problems. For example, if the 80,000-lb weight limit is eliminated, trucks of the future may include unusual features such as spread tandem axles, tri-axles, dual steering axles, and self-steering belly axles. Before consideration can be given to removing the 80,000-lb cap, the safety implications of such an action must be determined. Issues to be studied include braking, stability, and steering control.

Objective

The objective would be to identify possible truck configurations that would be feasible under various possible changes in the size and weight limits and to evaluate the dynamic properties of such configurations using vehicle simulation.

Evaluation of Accidents Involving Larger Combination Trucks on Designated Federal-Aid Highways

Background

To determine whether the current system of designated highways for western twins and other federally mandated vehicles can be expanded in the future or should be reduced to eliminate unsafe segments, an accident study to evaluate the operation of larger trucks on the current system is necessary. As noted previously, a plan for the conduct of this study is currently under development.

Objective

The objective would be to determine the accident experience of large combination vehicles on the designated system of Federal-Aid Highways.

In this paper the history, goals, and status of the FHWA truck safety research program have been reviewed. Some fairly complex and important studies and issues have been briefly described.

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