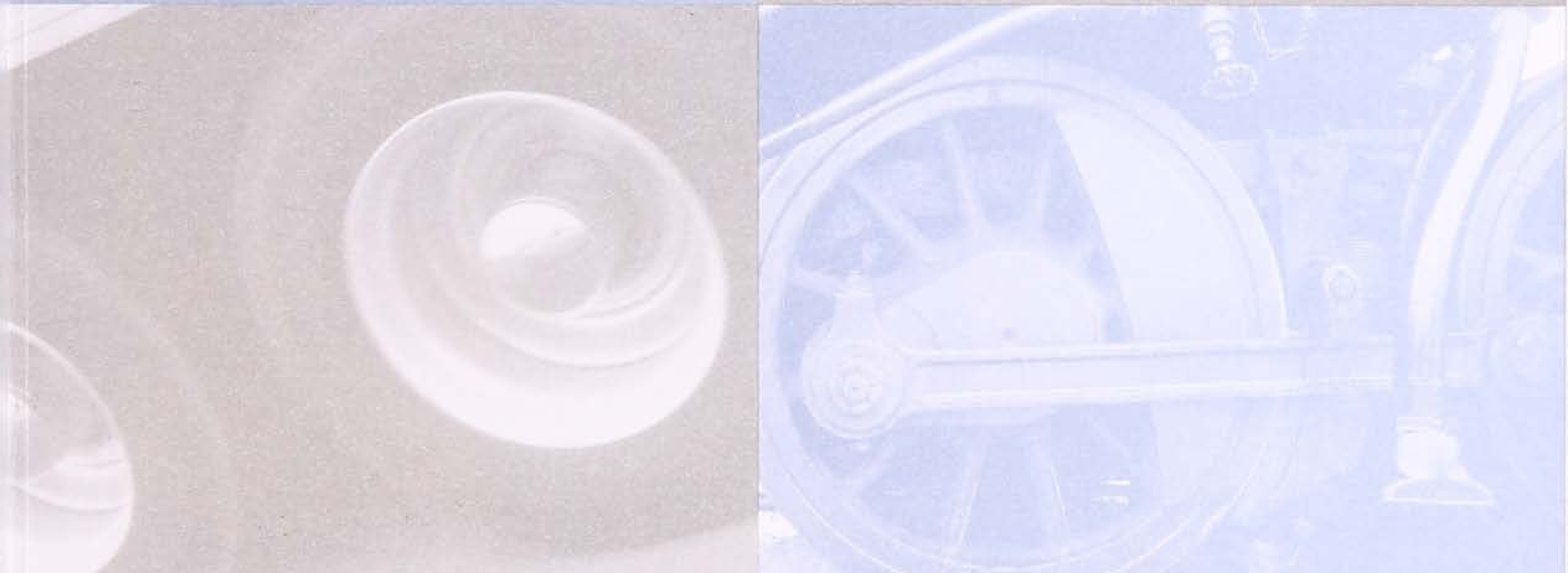
Safety Policy Considerations



in Truck and Rail Freight Transportation

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PREFACE

Comparatively low-cost freight transportation has been an important element in the growth of the United States economy. Goods can be transported between most points in the country quite cheaply and efficiently. To varying degrees, however, freight transportation services generate costs that are borne by society. One of the most significant of these costs is safety. In recent years, over 4,000 persons have been killed each year in mishaps involving truck and rail freight transportation and many more have been injured.

The objectives of this monograph are to examine the nature of the safety costs imposed by surface freight transportation and to suggest public policies that can help make it safer. We begin with an overall analysis of crashes and accidents involving the two surface freight modes. To gain a broad perspective, we look at the safety costs per mile traveled and for a ton-mile of freight shipped by truck or rail nationally. Our analysis thereby serves as a benchmark against which more localized cost estimates can be compared.

We examine crashes involving multiple-trailer combination trucks in addition to the more common single-trailer combination trucks. Because of the current policy debate regarding more permissive regulations for longer combination vehicles (LCVs), we assess the conditions under which multiple-trailer trucks have had a different crash incidence than single-trailer units. We also consider the issue of LCVs operating on two-lane highways en route to or coming from the shipping facilities they would serve.

The research reported in this monograph is an extension of a 1998 monograph, *External Costs of Truck and Rail Freight Transportation,* by David Forkenbrock. The purpose of that monograph was to comprehensively estimate both private (experienced directly by the transportation carrier) and external costs (uncompensated negative effects on other people). These estimates defined how much private costs would increase if external costs were internalized.

Our research was carried out at the University of Iowa Public Policy Center. Funding for this research was provided by the Office of the Secretary, U.S. Department of Transportation.

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Data needs for this project were extensive. Daniel Blower of the University of Michigan Transportation Research Institute provided us with a large and rich data file on fatal crashes involving trucks of varying sizes and weights. Completion of this study would have been much more difficult without the assistance of Ben Goldsworthy and David Harkins, graduate students at the Public Policy Center. They were highly enterprising and thorough in helping us find necessary data.

Teresa Lopes, editor at the Public Policy Center, ensured that the text is accessible to a wide audience, while maintaining the monograph's technical accuracy. Kathy Holeton, administrative assistant at the Center, helped us in too many ways to mention. She made our jobs a lot easier.

With real appreciation, we acknowledge the many and diverse contributions of these people.

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CHAPTER 1
INTRODUCTION

Freight transportation contributes to the quality of people's lives by making a wide array of goods and services available. To differing degrees, modes of transportation that move freight also produce social costs in that their operations affect the health and safety of people who travel, live, or work in proximity to the routes on which freight transportation operates. It is good public policy for society to try to minimize any adverse effects of moving freight while ensuring that goods are moved effectively.

In this monograph, we focus on one of the most important social costs, crashes and related safety problems. Crashes kill or injure travelers and others and damage their property. They also substantially reduce the efficiency of surface transportation. We first compare truck and rail–the two primary transportation modes used to transport freight in the United States–in terms of their safety costs per mile traveled and per-ton mile transported.

Following this general comparison, we turn our attention to safety issues related to freight trucks operating on public highways. Our analysis of motor carrier safety has two components:

- a comparative analysis of the involvement in fatal crashes of single-trailer combination trucks and of two- or three-trailer trucks and
- the magnitude of safety problems likely to arise if longer combination vehicles (LCVs) were to be allowed to travel on two-lane highways.

We are not proponents or opponents of increased LCV use; rather, our analysis is offered as a means of assessing the conditions under which LCVs are likely to be safe and those under which they are not.

MODAL COMPETITION

An important implication of our research is that one freight mode may be safer than another. To the extent that this is true, a question arises as to whether the safer mode could at least in part replace the less safe mode, thereby improving public safety. In general, rail and trucking compete in markets involving distances that are relatively short for rail yet relatively long for trucking. Most often, the value (dollars per ton) of freight shipped by truck is higher than that shipped by rail. One must recognize that our general unit of analysis, the ton-mile, includes a very wide array of goods.

Figure 1-1 provides an estimate of the amount of freight (measured in ton-miles) shipped in the United States by long-haul truck and freight rail in 2000. Of particular interest are the shaded portions of both pie charts: 41 percent of long-haul truck ton-miles are competitive with rail, and 33 percent of rail ton-miles are competitive with truck (Abacus Technology Corp. 1991, Exhibit 5-1). If the approximate proportions of this earlier estimate remain, about 664.9 billion ton-miles shipped in 2000 were modally competitive[1].

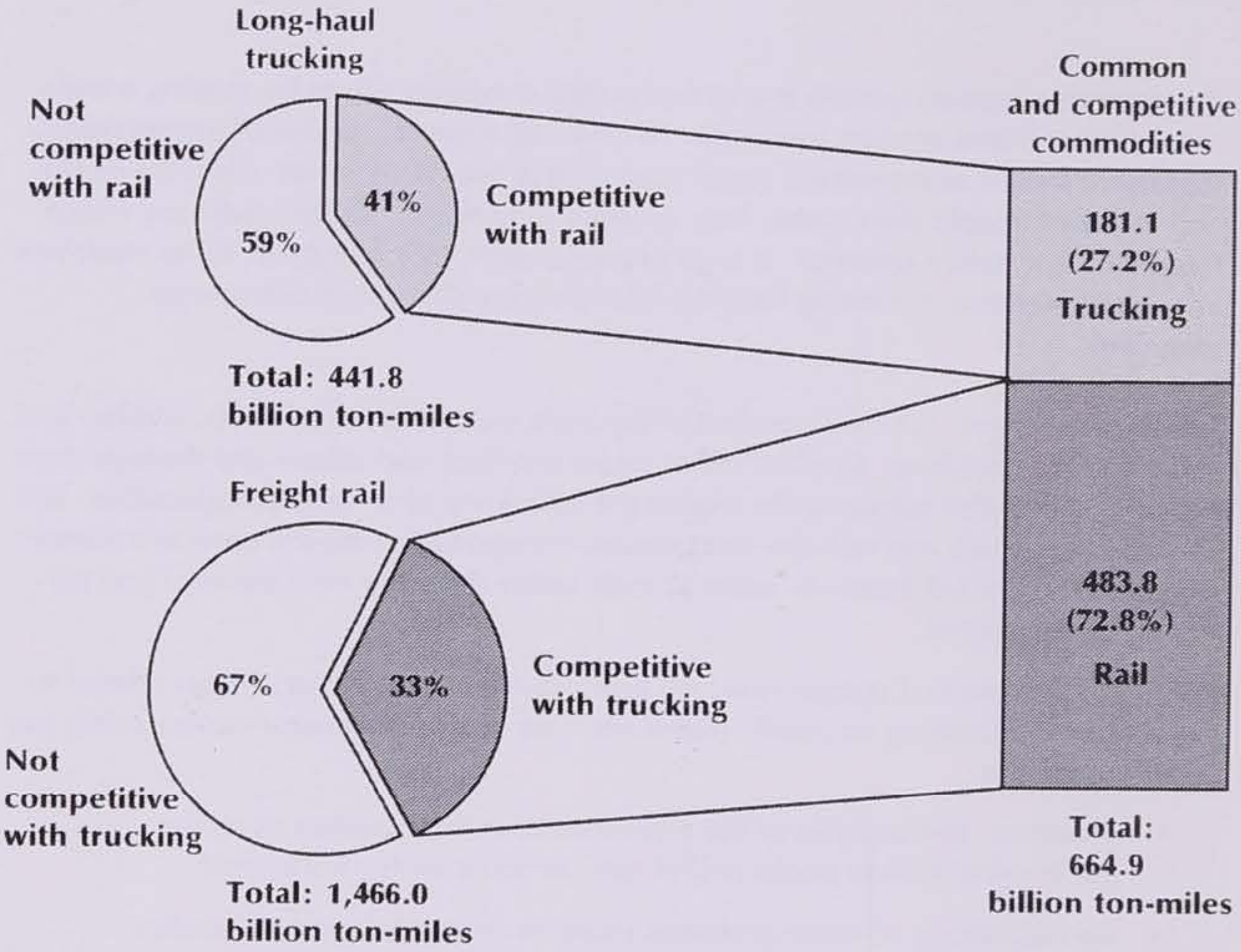

Figure 1-1. Competitive freight service for truck and rail, 2000

Sources: ATA (2001, Summary Table II) and AAR (2002, p. 2). Percentage modal competitive estimates are for 1987 from Abacus Technology Corporation (1991, Exhibit 5-1). Freight rail ton-miles are for Class I railroads, and trucking ton-miles are for truckload (TL) general freight carriers, the best approximation of long-haul trucking.

If through pricing, regulation, or any other mechanism, public policy were to encourage increased use of one mode, the extent of any resulting shift in modally competitive freight in a given market would depend on several factors, including:

- the magnitude of change in relative prices for various types of shippers,
- the difference in quality of service provided by competing modes, and

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[1] The figure of 441.8 billion ton-miles in Figure 1-1 is a subset of the 2,028.1 billion ton-miles considered in the safety analysis in Chapter 2. The former figure represents only truckload general freight, and the latter figure includes travel by all combination trucks. Both figures are based on an average load of 15.0 tons (ATA 2000, Summary Table III). This load estimate must be regarded as a gross estimate.

- specific requirements on the part of shippers.

Aggregate estimates of these factors would be difficult to make. Thus, the change in modal shares if any form of public incentive were instituted can only be speculated on. We must stress that our interest in this monograph is to estimate the approximate nature and magnitude of safety costs; it is not our objective to argue for greater use of one mode or another.

Marginal Versus Average Costs

When we estimate safety costs in Chapter 2, ideally we would examine the marginal cost to society of deaths, personal injuries, and property damage that arise from one more unit of freight transportation service. If at the margin, a freight carrier were paying user charges that equal the marginal social cost of the unit of freight, including safety-related costs, the provider of the transportation service would be paying appropriately from a societal perspective.

As the Transportation Research Board (TRB 1996, p. 2) observed, a marginal cost perspective is quite different from that used in highway (and other) cost allocation studies. Such studies are intended to determine how the costs of providing government facilities and services should be distributed equitably among different vehicle classes. In contrast, a marginal cost perspective is concerned only with whether the costs borne by society are fully assigned to those generating them. Marginal social cost pricing may be equal to, higher than, or less than the budgetary cost of government for providing facilities and services.

As a practical matter, it is difficult to develop accurate estimates of the marginal social costs of crashes and accidents relative to freight transportation. For example, good data are available on the number of fatalities and personal injuries associated with 100 million miles of truck operations. Thus, the average crash cost per vehicle-mile can be derived; and using average load factors, average cost per ton-mile can also be calculated. The marginal accident cost of one more truck vehicle-mile or ton-mile is much more difficult to estimate. Trip-specific considerations such as traffic volume on the roadway, design of the roadway itself, weather conditions, and factors peculiar to the truck and driver all enter the picture.

Estimates of marginal social costs are most valid when they pertain to very specific circumstances. In its report on marginal social costs of freight transportation, TRB (1996) used four specific case studies and stressed the limitations of these studies in making general conclusions about marginal social costs. TRB recommended (p. 125) an expanded array of case studies to increase what is known about the social costs of freight transportation.

In our analysis of comparative safety costs, we use average costs largely derived from aggregate data. While our estimates lack the precision of a more specific case study, these estimates provide an overall sense of the magnitude of various types of costs generated by freight trucks and rail nationally. Stated differently, unless one is able to accurately estimate the marginal social costs of each unit of transportation (e.g., each ton-mile) in widely varying circumstances, two choices are possible: One is to ignore costs to members of society other than the carrier and estimate user charges and taxes solely on the basis of public facility use; the other is to accept a degree of cross-subsidization within each transportation mode (i.e., not all vehicles will pay an identical fraction of the costs they impose because the user charge system is not sufficiently precise). We tend toward the second option: developing conservative estimates of average social costs at the national level. Our approach thus can serve as a benchmark against which case-specific estimates can be compared.

OVERVIEW

Chapter 2 contains an analysis of crash costs involving each of the two transportation modes. This aggregate analysis enables us to assess the relative safety of freight transportation using trucks versus rail. To provide an approximate estimate of the overall costs to society of crashes involving each mode, we apply commonly accepted dollar amounts for the value of preventing one more fatality, personal injury, or property-damaging crash.

Building on the previous chapter, we focus on fatal crashes involving freight trucks in Chapter 3. Specifically, we explore the conditions present in a total of 5,889 fatal crashes involving combination trucks to examine the extent to which conditions vary for crashes involving single-trailer combination trucks and those involving multiple-trailer combination trucks.

Chapter 4 continues our analysis of safety issues related to freight trucks, focusing on potential dangers posed to other vehicles if longer-combination vehicles (LCVs) were allowed to operate on two-lane highways as they pick up or drop off freight at facilities connected to interstate and other major highways.

In Chapter 5, we synthesize the results of the previous chapters and draw implications for national transportation policy related to trucking and rail.

CHAPTER 2
CRASHES AND ACCIDENTS

All transportation modes occasionally are involved in accidents and mishaps of various sorts. When this occurs, people and their property tend to experience adverse outcomes. The cost to society of a unit of transportation service (e.g., a vehicle-mile or ton-mile) due to crashes or accidents includes the uncompensated costs of deaths, injuries, and property damage that occur when an additional trip is made by the mode in question.

It is not possible to provide completely accurate estimates of the marginal crash costs of moving a unit of freight by truck or rail. Inaccuracies stem from the effects of various types of traffic on the crash or accident rates of other travelers and non-traveling populations.[1] Records can be examined to measure freight truck or train involvement in motor vehicle crashes, but there is no systematic way to determine what role they played in these events. If the primary cause of a crash is another vehicle, a pedestrian, or conditions external to vehicles (e.g., severe weather), an involved truck or train may not have precipitated the incident. On the other hand, its presence may have contributed to costs experienced by other travelers or persons.

It is important to stress that fault is not at issue. Whether a truck or train involved in an accident was completely free of blame or whether it caused the crash or accident is irrelevant to our analysis. Regarding the issue of fault, in a classic work, Vickery (1968) concluded:

> (I)n most of the accidents with which we are concerned there are two or more parties involved, and the damage involved in the accident could have been totally avoided if any party had acted differently, whether by driving less recklessly in the case of the "guilty" party, or by driving more defensively in the case of the "innocent" party, or by accomplishing the purpose in some way not involving the specific activity at all, as by traveling by train rather than automobile, or by living closer to one's place of work, or even giving up the object of the trip entirely... Systems which require payments by the actors only in the case of fault and only to the extent of the compensation received by others (even with the expenses of adjudication and administration added) fail to

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[1] Much of the recent literature on safety uses the term "crash" in lieu of "accident." When referring to motor vehicle incidents, we adhere to this modern terminology. In the case of pedestrians being struck by trains, however, it seems more logical to refer to these events as accidents, in that a person does not really crash into a train. When discussing safety in a broader context, we use both terms because motor vehicle collisions and pedestrians being struck, among other phenomena, are included.

> give an adequate incentive for seeking out alternatives not involving the increased risk of vehicular accident (pp. 466–467).

The real point is that the social cost would not have arisen had the particular transportation service not been provided. Thus, a fatality or injury bears the same societal cost whether the affected person is an employee aboard a train or truck, an occupant of another vehicle, or a pedestrian.

Our approach is to estimate total crash or accident costs to society, per unit of service provided, that result from crashes and accidents for each of the two transportation modes being studied. Costs to society consist of fatalities, personal injuries, and property damage. We provide data on the number of events and apply cost estimates to arrive at total estimated costs.

THE COST OF CRASHES AND ACCIDENTS

It is unpleasant to think of fatalities or personal injuries in monetary terms, but that is what must be done if one is to estimate the cost to society of accidents. Considerable work has been devoted to conceptual issues related to placing a value on saving human lives and preventing personal injuries. Generally, the approach that is becoming dominant is "willingness to pay."[2] According to this concept, the cost of a particular type of accident is the amount people would pay to reduce the risk of it happening.

To estimate willingness to pay for risk reduction, one observes market trade-offs in the amount people pay for risk reduction versus other goods. Because some people would be willing to pay more for a good than the asking price (that is, they enjoy what economists refer to as consumer surplus), the amount that people pay for the good is a lower-limit estimate of the value that they place on it.

For example, suppose we observe that four million people pay $100 each for a safety enhancement on the new cars they buy. Further, suppose the buyers expect this enhancement to reduce their chances of fatal injury by one in 4,000 over the period that they will be using the cars. As a group, the buyers expect their $400 million investment to save 1,000 lives. Collectively, the buyers have demonstrated a willingness to pay $400,000 per life saved.

A report prepared for the Federal Highway Administration by the Urban Institute (Miller et al. 1991) summarized the results of numerous studies of the value of risk reduction. The values suggested by Miller et al. are widely used as estimates of the economic value of reducing the risks of motor vehicle crashes. Miller et al. expressed their suggested values in 1988 dollars; in Table 2-1 we present their values in 2000 dollars, having applied the Gross Domestic Product (GDP) deflator. These are the values used in our analysis. While the value to society of saving a

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[2] For discussions of the willingness to pay concept of value, see Viscusi (1993), National Safety Council (1993), Jones-Lee (1989), and U.S. Office of Management and Budget (1991).

statistical life in 2000 dollars is \$3,200,549, in our analysis, we use a value of \$3,000,000 at the request of the U.S. DOT. This is the value it currently uses in safety analyses.

Table 2-1. Cost of crashes and accidents (2000 dollars)

Accident type	Per person	Per crash
Fatal	3,000,000	3,413,507
Personal injury	62,004	93,086
Property damage	2,326	6,005

SOURCE: Personal injury and property damage figures are from Miller et al. (1991), inflated to 2000 dollars.

Estimated external accident costs per ton-mile for freight trucks and trains follow.

Motor Carriers

Evidence suggests that motor vehicle crash rates for fatal, personal injury, and property damage crashes increase with traffic volume up to a certain level of traffic, about 7,000 vehicles per lane per day (Hall and Pendleton 1990). Forkenbrock and Foster (1997) estimated the relationship between average daily traffic (ADT) per lane and crash rates per million vehicle-miles of travel (VMT). Using semi-logarithmic regression and data on 17,767 rural non-interstate highway segments with ADT per lane ranging from 50 to 5,000, they found a significant positive association between traffic volume and crash rate. For example, a highway with 4,000 ADT per lane would have a crash rate 47.4 percent higher than one with ADT per lane of 2,000 (p. 87).[3] This suggests that the marginal crash cost occasioned by one more vehicle operating on most roads and highways will exceed the average of those already on the roadway. Because of data limitations, however, this analysis is based on average crash costs and, therefore, may have a downward bias in terms of the marginal cost of a vehicle trip.

According to the Federal Motor Carrier Safety Administration, during 2000 combination trucks (the large preponderance were freight trucks) were involved in crashes that resulted in 3,980 fatalities and 73,000 personal injuries (FMCSA 2002, Tables 13 and 15). In Table 2-2, we summarize the crash involvement of these vehicles in fatal, personal injury, and property damage only (PDO) crashes.[4] In 2000, combination trucks were involved in 2.7 fatal crashes, as well as 37.0 personal injury crashes and 126.5 PDO crashes, per 100 million miles of travel.

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[3] See also Lundy (1965) and Ceder and Livneh (1982). These authors also found a positive association between traffic volumes and accident rates.

[4] Note that the foregoing numbers are total fatalities and injuries. Table 2-2 contains the total number of crashes. On average, more than one person is killed in fatal crashes or injured in personal injury crashes.

Applying the per-crash values in Table 2-1 to the number of fatal, personal injury and PDO crashes, in Table 2-2 we obtain a total cost to society of over $18.3 billion. The average cost to society of crashes related to combination trucks in 2000 was 13.56 cents per ton-mile (based on a total of 135,208,000,000 vehicle miles [FMCSA 2002, Table 13] and an average load of 15 tons [ATA 2000, Summary Table II]).[5] It is important to stress that this is not the net external cost to society; that would be equal to this cost minus any compensation paid by the trucking industry to those harmed by these crashes or to their families. Estimates of these net external costs of freight trucking for 1994 appear in Forkenbrock (1998).

Table 2-2. Crash rates and costs of large trucks, 2000

	Fatal	Personal injury	Property damage	Total
Number of crashes	3,708	50,000	171,000	224,708
Per 100 million VMT	2.7	37.0	126.5	166.2
Societal cost (billions of 2000 dollars)	12.637	4.654	1.027	18.338
Societal cost per vehicle-mile (2000 cents)	9.36	3.44	0.76	13.56
Societal cost per ton-mile (2000 cents)	0.62	0.23	0.05	0.90

Source: Crash data are from FMCSA (2002, Tables 13, 15, and 16). Ton-miles are derived from ATA (2000, Summary Table II) and FMCSA (2002, Table 13).

Freight Rail

Crashes or accidents involving freight trains fall into three primary categories:

- collisions at highway-rail grade crossings,
- persons struck by a train at other locations, and
- crashes involving the train alone.

As Table 2-3 indicates, in 2000 647 people lost their lives in crashes or accidents involving Class I freight rail (i.e., excluding Amtrak, the only Class I passenger railroad), and 6,243 were injured. The most frequent type of fatal crash involving all Class I railroads is striking persons at locations other than grade crossings. No distinction is made here between trespassers and non-trespassers, though it should be noted that for all railroads taken together, trespassers accounted for 463 fatalities

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[5] The 15-ton figure factors in empty or less-full backhaul operations. The key assumption here is that the trucking firms included in the ATA tabulations are representative of the entire industry.

in 2000. Another major cause of fatal accidents is train collisions at highway-rail grade crossings (425 fatalities in 2000).

Using the same values for the costs to society of these fatal and personal injury casualties as in the analysis of freight trucking, we estimate the costs of rail crashes and accidents to be $1.941 billion and $387 million, respectively (see Table 2-3). Property damage resulting from train accidents is difficult to estimate. One estimate of the value of property damage to other vehicles involved in crashes with trains at highway-rail grade crossings is provided by the Bureau of Transportation Statistics (1997, Table 3-2) based on Federal Railroad Administration data. Updating data available for earlier years, we estimate the figure for 2000 to be approximately $20 million.[6] We assume that property damage for non-crossing rail accidents, other than that to trains, is comparatively minor and ignore the costs of such damage. The total societal cost of railroad accidents in 2000 dollars was about $2.348 billion. Based on the ton-miles shipped by Class I freight rail in 2000, 1.466 trillion (AAR 2002, p. 2), we estimate a total per-ton-mile societal cost of 0.16 cents.

Table 2-3. Costs of crashes and accidents involving Class I freight rail, 2000

	Fatal	Personal injury	Property damage	Total
Number of people	647	6,243	–	6,890
Societal cost (billions of 2000 dollars)	1.941	0.387	0.020	2.348
Societal cost per ton-mile (2000 cents)	0.13	0.03	0.00	0.16

SOURCE: Fatality and injury data are from FRA (2001, Tables 3-2 and 3-4); ton-miles are from AAR (2002, p. 2).

CONCLUSIONS

This chapter has explored the relative performance of freight trucking and rail with regard to safety. To make such a comparison, a common unit of measurement is needed; we use the ton-mile while recognizing that it is an imperfect measure. Most importantly, it stands to reason that the many trucks operating on public roadways have a much greater exposure to crashes than do the far smaller number of trains operating on private rights-of-way with only limited potential for conflict with other modes of transportation. Yet, our analysis reveals that on a per-ton-mile basis, combination trucks impose a crash-related cost to society that is over 5.6 times greater than the cost imposed by freight rail. We should note that our crash data pertain to combination trucks, not freight trucks per se. According to the

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[6] It is not possible to determine precisely what portion of this amount arose from operations of Class I railroads, but we estimate the portion to be upwards of 90 percent.

American Trucking Association, however, general freight trucks account for over three-quarters of the ton-miles generated by Class I (larger) trucking firms nationally.

In Chapter 1, we cited an estimate that approximately 41 percent of the ton-miles shipped by truck are competitive with rail (i.e., they could feasibly have been shipped by rail) and 33 percent of the ton-miles moved by rail are competitive with freight trucking. This suggests that (1) the safety-maximizing public policy would be to encourage shipping by rail whenever it is feasible to do so and (2) a substantial number of ton-miles could possibly be diverted, potentially reducing the crash costs to society by an impressive amount.

CHAPTER 3
FATAL CRASH INVOLVEMENT BY MULTIPLE-TRAILER TRUCKS

We have seen that freight trucks have a four-fold higher per-ton-mile societal cost related to fatal, personal injury, and PDO crashes than do freight trains. Focusing on heavy freight trucks in this chapter we compare (1) the circumstances under which fatal crashes have occurred involving multiple-trailer trucks with (2) those surrounding such crashes when conventional single-trailer freight-carrying trucks are involved. The Intermodal Transportation Efficiency Act (ISTEA) of 1991 and the later Transportation Equity Act (TEA–21) of 1998 have effectively banned the use of longer combination vehicles (LCVs) in states that had not legalized them prior to passage of ISTEA (i.e., before June 1, 1991). The primary reason for the bans is concern that LCVs are less safe than other combination trucks. Such concerns stem in part from the fact that occupants of passenger vehicles involved in crashes with large trucks tend not to fare well. In 2000, 3,446 passenger vehicle occupants died in crashes with large trucks while 534 occupants of combination trucks were killed (FMCSA 2002, Table 13).

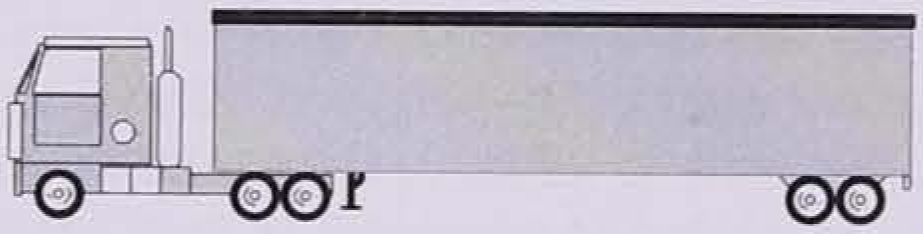
Advocates of LCVs contend that the applicable bans should be lifted in the next transportation reauthorization act in 2003. They stress the potential for substantial freight cost savings as more cargo could be moved per unit of labor, energy, or equipment. Thus, the policy debate involves balancing safety concerns against prospects for more cost-effective freight transportation. This chapter addresses one aspect of the issue–that of safety. Because reliable data are not available on the actual vehicle miles traveled (VMT) by multiple-trailer trucks—much less data on travel under varying conditions (e.g., road type, weather, and traffic volume)—crash rates per unit of VMT cannot be compared.

Fortunately, good data exist on circumstances surrounding fatal crashes involving various types of freight trucks. A limitation of these data, however, is that they do not distinguish between shorter multiple-trailer trucks (STAA doubles, as discussed below), which are legal nationwide, and longer and heavier multiple-trailer trucks whose use is more restricted. Thus, our analysis is conservative in that many, perhaps most, of the fatal crashes involving multiple-trailer trucks in the data file do not involve the longer two- and three-trailer units that are of greatest concern by those opposing increased use of LCVs. Yet, our analysis does provide insights into the conditions under which multiple-trailer trucks have demonstrated a greater propensity to be involved in fatal crashes. How much more the differences in crash experiences would be between multiple- and single-trailer trucks if the former were strictly LCVs is unclear, but it is not unreasonable to suppose that these differences would be greater.

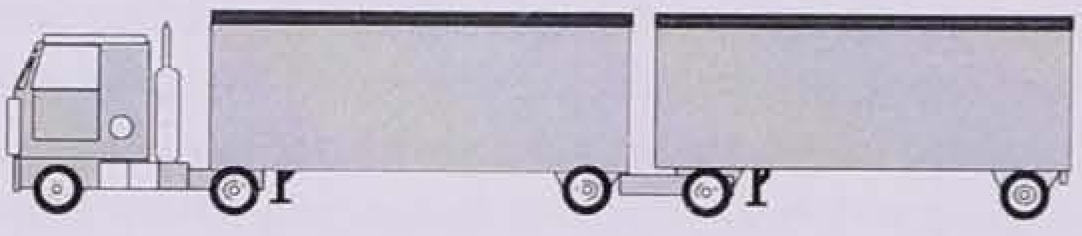
A TAXONOMY OF FREIGHT COMBINATION TRUCKS

Before proceeding with the analysis, it is useful to more fully define the sorts of freight trucks included in our data file. Figure 3-1 depicts various truck configurations. The base unit for this analysis is the standard single-trailer truck, most often with a 48- or 53-foot trailer (about half of the states restrict trailer length to 48 feet). This configuration is by far the most common style of combination freight truck in service within the United States, and it usually has a weight limit of 80,000 pounds. Occasionally, the trailer will have a three-axle configuration in lieu of the two axles shown in the figure. The Surface Transportation Assistance Act of 1982 requires states to allow trucks pulling twin 28- or 33-foot trailers with a maximum weight of 80,000 pounds to travel on interstate highways and other principal roads. As a result, these double-trailer units are commonly referred to as "STAA doubles." The 1982 act increased mandatory allowable trailer widths from 96 to 102 inches, as well.

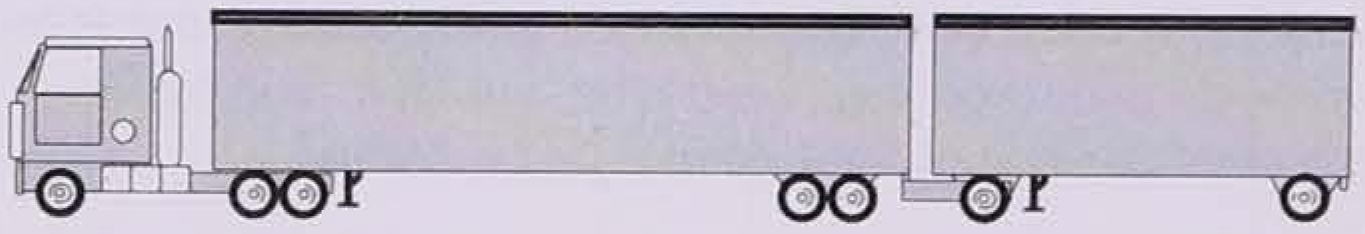
Standard 48-foot semitrailer



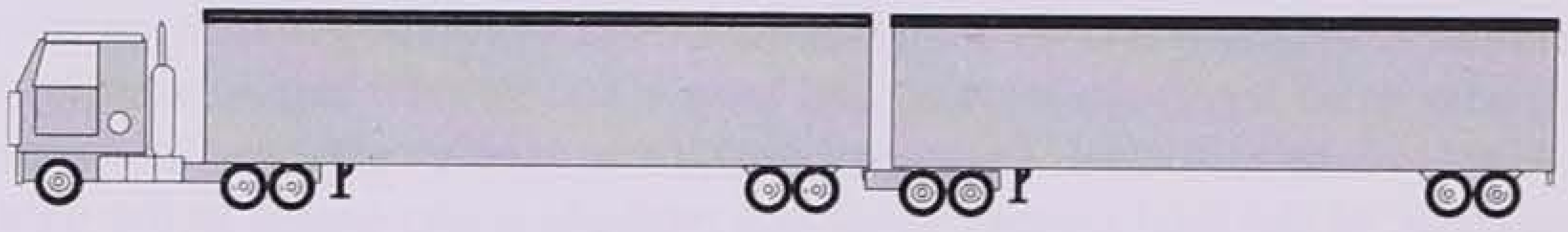
Double 28-foot trailers



Rocky Mountain double



Turnpike double



Triple 28-foot trailers

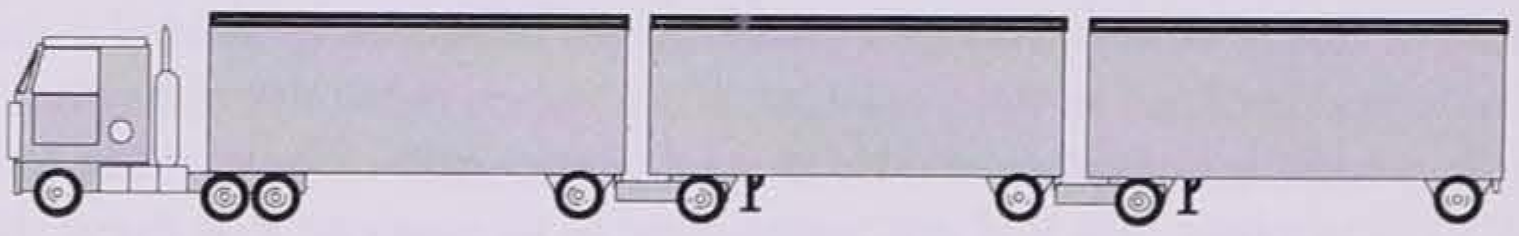


Figure 3-1. Categories of combination trucks

Twenty-one states, mostly in the West and Northwest, now allow so-called "Rocky Mountain double" vehicles with one tandem-axle 48- to 53-foot trailer and a second single-axle 20- to 28.5-foot trailer . They generally are allowed to operate at up to 120,000 pounds. Longer "turnpike double" configurations are allowed in 19 states, mostly the same states that allow Rocky Mountain doubles. Turnpike doubles have two long trailers of equal length, typically from 40- to 53-feet, and overall lengths of approximately 120 feet, with allowable weights of up to 147,000 pounds (weight limits vary considerably among the states that allow them). Generally, operation of these units is limited to interstate highways and toll roads. They are used primarily by truckload (TL) carriers, who transport freight from origin to destination without intermediate pick-up or delivery.

Triple-trailer combination trucks usually have three 28-foot trailers, each with two axles. Currently, 14 states allow triples, but they restrict their use to interstate highways, as well as other four-lane highways with low traffic volumes. The most extensive use of triples is by less-than-truckload (LTL) carriers that move smaller shipments between multiple origins and destinations. These units are likely to fill up before they reach gross weight limits.

We must stress that the data used in our analysis do not distinguish between the various types of doubles, which can vary greatly from STAA doubles to turnpike doubles that have total lengths of up to 120 feet (Caltrans 2001). As a practical matter, however, STAA doubles far outnumber longer doubles in terms of vehicles in operation. The U.S. DOT (2000a, Table 1) estimates that in 2000, STAA doubles accounted for 68 percent of all double units in operation and 71 percent of the miles traveled by doubles. Thus, our data can provide only limited insights into the specific crash circumstances of Rocky Mountain doubles and turnpike doubles. Furthermore, because most of the states currently allowing LCVs place varying restrictions on the types of roads and the conditions under which they can travel, our data may not provide a completely accurate picture of the crash profile that would result if fewer restrictions were placed on LCVs or if these vehicles were allowed to operate in the same manner as other combination trucks. In particular, the U.S. DOT stresses that "crash rates for larger vehicles in use in certain regions of the country or on turnpikes may not be transferable to operations in other parts of the country where traffic volumes are higher and the operating environment is less safe" (U.S. DOT 2000a, p. 21).

PREVIOUS STUDIES

The Federal Highway Administration (FHWA 1985, Chapters III and IV) cited safety concerns of LCVs pertaining to passing, braking, and vehicle handling and control. To date, however, little objective research has been carried out on the relative safety of LCVs. At about the time ISTEA froze the expansion of LCV use by the states, the U.S. General Accounting Office (U.S. GAO) concluded that the relative safety of LCVs was "largely unknown" because of inadequate reporting of crashes. It noted that nine previous studies found LCVs to be anywhere from 21 percent less likely to be involved in crashes to 66 percent more likely when compared to single-trailer trucks (U.S. GAO 1992, p. 6). Likewise, the Transportation Research Board

(TRB 1990, pp. 126–127) cited various studies that found crash involvement rates of double-trailer trucks to range from 20 percent less to 20 percent more than those of single-trailer trucks. The U.S. DOT (2000b, p. VIII-2) noted the paucity of analyses comparing LCV crash rates with those of other combination trucks, observing that the limited work to date has not taken into account road type or area (urban or rural). It stressed the likelihood that these two factors play significant roles in large truck crashes.

Harkey et al. (1996, p. 27) suggested several important areas where more needs to be known about LCV safety, including operation on congested freeways and at rural and urban intersections. Compounding the uncertainty as to the relative safety of LCVs is the observation by the U.S. GAO (1992, pp. 7, 40) and Geuy (1989) that the limited safety experience to date with LCVs may not be representative of the record that would materialize with much wider use. They have noted that currently special permits are required, which encourage better equipment and more experienced drivers, and that LCVs operate on high-standard highways and tend to be withheld from foul weather conditions.

Using the best available information, the U.S. DOT has estimated that trucks pulling two or more trailers are likely to have fatal crash rates that are about 11 percent higher than single-trailer truck rates (U.S. DOT 2000b, p. VIII-5). In making this estimate, the crash histories of multiple-trailer trucks were adjusted to take into account differences in operating circumstances between these trucks and single-trailer trucks. The U.S. DOT estimate is intended to reflect the outcome of allowing multiple-trailer combination trucks to operate under the same provisions as single-trailer trucks. Zaloshnja et al. reported that the severity of crashes involving trucks pulling two or more trailers is greater than for single-trailer trucks. On average, 1.118 persons are killed in crashes involving multiple-trailer trucks compared to 1.109 for single-trailer units (Zaloshnja et al. 2000, Table 3). The average per-crash cost for multiple-trailer trucks is $117,309 while the figure for trucks pulling a single trailer is $84,588 (Zaloshnja et al. 2000, Table 11).

The California DOT (Caltrans 2001, p. 2) tested a series of safety-related performance attributes of LCVs and concluded that the following problems exist: triples are more likely to whip and sway, and Rocky Mountain doubles and turnpike doubles tend to have difficulty tracking on curves. The American Automobile Association (Lankard and Lehrer 1999, p. 6) cited the Caltrans tests as indicating that it takes up to 10 percent longer to safely pass an LCV than a single-trailer truck. This would imply that passing safety would be an especially serious issue on curves or slopes of two-lane roads where horizontal visual ranges are most limited. A related issue observed in the Caltrans test is the difficulty LCVs have in maintaining speed on uphill gradients of 5 percent or more. The test indicated that other trucks pull out into passing lanes to overtake the LCVs, backing up traffic and creating potentially unsafe conditions.

A final aspect of safety related to LCVs pertains to human factors. A study by the Battelle Human Factors Transportation Center (1997) involved a controlled field experiment to evaluate stress and fatigue associated with operating two different configurations of triple-trailer LCVs in comparison to a standard single-trailer truck under typical operating conditions. Triples were found to be more likely to contribute to fatigue and performance degradation in terms of the two criteria applied: probability of lane exceedance and operator workload. Fatigue differences were found to carry over into the next workday. The study concluded, "with regard to triple versus single-trailer configuration differences in fatigue, analyses revealed a consistent pattern of statistically significant ($p < 0.05$) results across all variables" (p. iii). This result is consistent with an earlier survey of truck drivers conducted by TRB. When asked about "potentially risky" situations, 84 percent of the drivers with extensive experience with double-trailer trucks found them more likely to sway on an open roadway, and 80 percent cited magnified trailer movement in response to abrupt steering (TRB 1986, Table 4-9). Seventy-nine percent of the experienced drivers felt that double-trailer units are more difficult to operate on slick pavement, and 78 percent said they are more difficult to control in emergency braking (Table 4-8).

In summary, there is some evidence that LCVs are less safe than standard single-trailer combination trucks, but more needs to be known about the circumstances under which LCVs may be more prone to become involved in fatal crashes. This knowledge would be useful in two ways: (1) it would help in determining whether wider use of LCVs should be permitted and (2) if they were, it could help establish what restrictions should be placed on their operations.

DATA AND SAMPLING

Data used in our analysis are taken from the Trucks Involved in Fatal Accidents (TIFA) data file maintained by the University of Michigan Transportation Research Institute (UMTRI) for the years 1995–1998. The TIFA data file contains a random sample of crashes involving trucks of various configurations drawn from the federal Fatality Analysis Reporting System (FARS). FARS was first created by the National Highway Traffic Safety Administration (NHTSA) in 1975; it includes annual data on motor vehicle traffic crashes that result in the death of either an occupant of a vehicle or a non-motorist within 30 days of the crash. The crashes included involve a motor vehicle traveling on a roadway customarily open to the public. FARS data are gathered from the states using a standardized recording format.

The TIFA data file augments the FARS data with police reports on all fatal crashes involving at least one truck. These police reports vary considerably from state to state, so they are supplemented by telephone interviews. Whenever possible, the owner or driver of a vehicle involved in the crash is contacted; and failing that, the investigating police officer is contacted as necessary to lend as much detail and accuracy as possible to each case. As a result, the TIFA data file contains considerable detail on crash circumstances.

Given that our interest is in comparing the crash circumstances when multiple-trailer trucks were involved with those when single-trailer trucks were involved, we excluded cases involving single-unit (non-combination) trucks. We also excluded several other types of cases to ensure comparability between the two types of truck configurations examined in this analysis. Because multiple-trailer trucks are unlikely to be either government owned or daily rental units, we excluded these categories, retaining both private and for-hire trucks. Also, we excluded cases involving the owner as driver and vehicles registered as rental units.

Owner-operated trucks are far more often single-trailer trucks than multiple-trailer trucks, as are rental units. Anecdotal evidence suggests that these trucks may have a different safety record than the included categories—driver not owner, and vehicle registered as a business—which are by far the most common categories for both types of trucks.

With these exclusions, the data file contains fatal crashes involving 545 multiple-trailer trucks and 5,344 single-trailer trucks. We coded the dependent variable 1 = single-trailer truck and 2 = multiple-trailer truck and applied a weighting of ten for multiple-trailer crashes. This allowed us to have nearly an equal number of crashes involving each category of truck, and therefore a dependent variable with a mean value of 1.5. Having essentially an equal number of cases for each of the two categories of truck facilitates comparison of the circumstances present in the crashes involving each of them. The effective number of cases for the analysis is thus 10,794 (5,344 single-trailer truck and 5,450 multiple-trailer truck crashes). We carried out an analysis of these data using two complementary statistical methods, as described below.

Descriptions of the variables we included in the analysis are presented in Table 3-1. Also shown in the table are the respective categories for each variable and the percentages of crashes falling into each category. Essentially, the independent variables can be grouped into three sets: (1) road attributes, including posted speed limit and slope; (2) prevailing conditions, including roadway surface moisture and amount of light; and (3) other circumstances, including whether the crash occurred at an intersection (including interchanges on freeways or interstates), whether it happened in an urban or a rural area, and how many vehicles were involved in the crash. Variables related to alignment (straight or curve) and traffic flow (divided or not) proved to be redundant with the functional classification variable and were eliminated from the analysis.

METHODOLOGY

The approach taken in this research is to identify differences in the conditions under which multiple-trailer trucks have a greater propensity to be involved in fatal crashes than single-unit trucks. For this analysis, two complementary techniques developed at the University of Michigan are particularly appropriate: automatic interaction detector and multiple classification analysis.

Automatic Interaction Detector

An analytic technique known as the automatic interaction detector (AID) is used to identify likely interaction, thereby enabling any needed interaction terms to be included in the application of multiple classification analysis (MCA). Also, while

MCA assigns variation in the dependent variable to each of a series of predictor variables, AID focuses on improvements in prediction. Rather than examining the effects of a certain predictor variable while holding the others constant, AID searches for the single dichotomous split between categories of predictor variables that will produce a maximum improvement in ability to predict values of the dependent variable.

Table 3-1. Variables included in the analysis

Name	Description	Categories	Distribution (%)	
Trailer	Number of trailers pulled by truck	1 = 1 Trailer	5,344	(49.5)
		2 = 2 or 3 Trailers	5,450	(50.5)
Light	Prevailing light condition	1 = Daylight	5,800	(53.8)
		2 = Dark but lighted	1,047	(9.7)
		3 = Dawn or dusk	444	(4.1)
		4 = Dark	3,503	(32.4)
Vehicle	Number of vehicles in crash	1 = 1 Vehicle	2,186	(20.3)
		2 = 2 Vehicles	6,243	(57.9)
		3 = 3 or more vehicles	2,365	(21.8)
Speed	Speed limit at crash scene	1 = < 55 mph	2,349	(21.8)
		2 = 55 – 60 mph	4,691	(43.5)
		3 = 65 – 75 mph	3,754	(34.7)
Class	Roadway functional classification	1 = Interstate/Freeway	3,163	(51.2)
		2 = Arterial	3,275	(30.5)
		3 = Lower standard	1,982	(18.3)
Slope	Roadway slope	1 = Level	7,713	(71.5)
		2 = Not level	3,081	(28.5)
Intsn	Whether crash was at an intersection	1 = Not at an intersection	7,631	(70.6)
		2 = At or near an intersection	3,163	(29.4)
Setting	Whether crash was in urban or rural setting	1 = Urban setting	4,186	(38.9)
		2 = Rural setting	6,608	(61.1)
Surface	Roadway surface condition	1 = Dry	8,488	(78.7)
		2 = Wet	1,699	(15.7)
		3 = Snow, slush, or ice	607	(5.6)

Through a succession of binary splits, AID divides the sample into a series of mutually exclusive subgroups. Each observation, then, becomes a member of one and only one of these subgroups. The following description of the AID algorithm is based on Sonquist and Morgan (1964) and Sonquist et al. (1973):

(1) Select the as yet unsplit and untried sample group, group *i*, which has the largest total sum of squares. (The total input sample is considered the first, and indeed only, group at the start.)

(2) Find the division of the C_k classes of any single predictor X_k such that combining classes to form the partition *p* of this group *i* into two non-overlapping subgroups on this basis provides the largest reduction in the unexplained sum of squares. Consider all possible binary splits on all predictors with the restrictions that (a) the classes of each predictor are ordered into descending sequence, using their means as a key and (b) observations belonging to classes which are not contiguous (after sorting) are not placed together in one of the new groups to be formed.

(3) For a partition *p* on variable *k* over group *i* actually to take place after the completion of Step 2, it is required that the total sum of squares for group *i* be larger than a prestated fraction *P* of the original variance around the mean (usually a value of 0.6 percent is used). If this criterion is not met, group *i* is not capable of being split and the next most promising group (having the maximum total sum of squares) is selected via Step 1.

(4) If there are no more unsplit groups such that requirement *P* is met or if a split would result in a number of cases in a group less than a specified number (we used 50 cases), the process terminates.

Thus at each step of the analysis, groups are defined so as to minimize the unexplained sum of squares. The mean value for the dependent variable is calculated for each group. A characteristic peculiar to AID is that the division of the sample into subgroups occurs in a series of separate steps. The result is a tree-like definition of subgroups of ever-decreasing size as the analysis proceeds.

Multiple Classification Analysis

Multiple classification analysis (MCA) evaluates the interrelationships between several predictor variables and an interval-scaled or dichotomous dependent variable. Like multiple regression, MCA is able to show the effect of each predictor on the dependent variable with or without taking into account the contributions of other predictor variables. Unlike regression, MCA does not require interval-scaled predictor variables, linear relationships are not necessary, and distributions need not be bivariate normal (Andrews et al. 1967, p. 16). The MCA coefficients are expressed as adjustments to the grand mean of the dependent variable, as distinguished from dummy variable regression where the coefficients are expressed as deviations from the omitted single category.

The technique can be expressed as follows:

$$Y_{ijk} = \bar{Y} + a_i + b_j + c_k ... + e_{ijk}$$

where $\bar{Y}$ is the grand mean, a_i is the coefficient corresponding to the *i*th category of predictor *A*, b_j is the coefficient corresponding to the *j*th category of predictor *B*, c_k is the coefficient corresponding to the *k*th category of predictor *C*, e_{ijk} is a random error term, and Y_{ijk} is the observed score of a particular case that falls in the *i*th category of *A*, the *j*th category of *B*, the *k*th category of *C*, etc.

The objective is to determine the values for a_i, b_j, c_k, etc., which enable the observed values of the dependent variable, *Y*, to be predicted with a minimum of error using least squares criteria (Andrews et al 1967, p. 103). When the predictor variables are orthogonal (i.e., non-correlated), the values of a_i, b_j, c_k, etc., are simply the deviations of the various category means from the grand mean for the entire sample. In the more likely case where the predictors are non-orthogonal, a portion of the deviation from the grand mean associated with each predictor variable category actually is contributed by the predictor's correlations with other predictors in the model. In such cases, there is an excessive (i.e., artificially large) amount of variance in *Y* explained. MCA adjusts the values of a_i, b_j, c_k, etc., to compensate for this commonly explained variance.

The two techniques, AID and MCA, thus can be applied in tandem; each of them addresses a somewhat different question. In fact, the joint application of the two techniques is suggested by the designers of AID (see Sonquist 1970, Chap. 6). Applying AID first, one can determine whether interaction terms are needed in the MCA analysis. AID does much more than identify the presence of interaction, however. It enables the sample to be partitioned into groups on the basis of attributes and conditions associated with crashes involving each of the two categories of trucks thereby answering the question, "Which measures best define differences between fatal crashes involving single- versus multiple-trailer trucks?" MCA, on the other hand, enables us to ask, "How much of a percentage difference in crashes between truck categories does each of the measures bring about, both alone and when the effects of other measures are taken into account?"

ANALYSIS

To assess the role played by the several independent variables in explaining differences in the circumstances surrounding fatal crashes involving single-trailer versus multiple-trailer trucks, we apply AID first. The effects of the respective circumstances on differences in crash involvement are then assessed using MCA.

AID Analysis

Table 3-2 presents the results of the AID analysis. Node 1 contains the full sample, 10,794 cases, with a mean value of 1.50 for the dependent variable—crash involvement by the two different categories of combination trucks, single-trailer and multiple- (two or three) trailer trucks. The greater the amount by which the mean value of a given node below node 1 exceeds 1.50, the more likely the circumstances represented by that node are associated with a fatal crash involving a multiple-trailer truck, as opposed to one with a single trailer.

The greatest effect on the type of truck involved in a fatal crash lies in the functional classification of the roadway, with interstate highways being far more likely to be the site of a fatal crash involving a multiple-trailer truck. The most plausible explanation for this is that, as we noted earlier, the states allowing LCVs and even STAA doubles generally restrict them to interstate and other high-standard highways. It is worth noting, however, that only 58 percent of the fatal crashes involving multiple-trailer trucks occurred on interstate highways. Following the tree in Table 3-2 to the right, the maximum involvement by multiple-trailer trucks in fatal crashes is on interstate highways under conditions of darkness, with snow, slush, or ice on the road surface. These conditions produce a score in node 15 of 1.78, meaning that multiple-trailer trucks are 28 percent more likely to be involved in a fatal crash than is the overall sample. They also are 56 percent more likely to be involved in a fatal crash than are single-trailer trucks: 1.78 – 1.50 = .28, the fraction by which multiple-trailer trucks exceed the overall mean, plus an additional .28, the fraction by which single-trailer trucks fall below the overall mean, given that the two types of truck configurations are approximately equal in size within the sample.

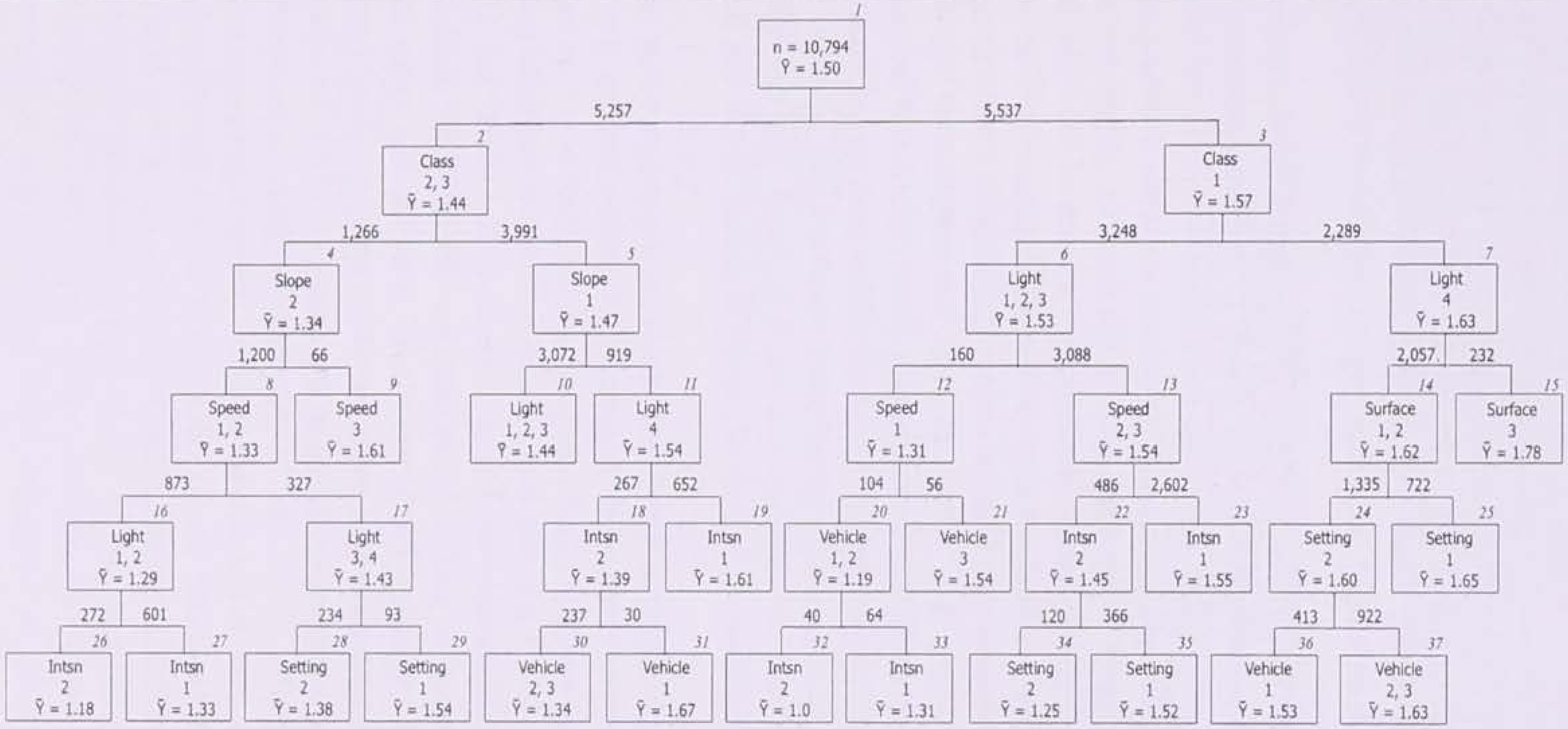
Under dry or wet (i.e., not snowy, slushy, or icy) pavement conditions in darkness on interstate highways in urban areas, multiple-trailer trucks are 15 percent more likely than the overall sample to be involved in a fatal crash (node 25). Likewise, node 37 indicates that under those conditions in rural areas when at least moderate traffic is present (indicated by up to three or more vehicles being involved in the crash), multiple-trailer trucks are 13 percent more likely than the overall sample to be involved in a fatal crash.

A comparatively low level of involvement by multiple-trailer trucks is seen in node 26, indicating a non-interstate highway, a sloped road, a 60 mph speed limit or less, good lighting, and an intersection. With these conditions, multiple-trailer trucks are 32 percent less likely to be involved in a fatal crash than is true of the overall sample. In similar fashion, relatively low multiple-trailer involvement is shown in node 30, signifying a non-interstate highway, a level segment, darkness, and a crash site at an intersection with two or more vehicles involved. Under these circumstances, multiple-trailer trucks are 16 percent less likely to be involved in a fatal crash than is the overall sample.

It is difficult to fully separate the conditions that are inherently dangerous for multiple-trailer trucks from those that are simply the conditions under which these trucks operate most frequently. Perhaps the most useful information in Table 3-2 lies in the nodes representing conditions under which multiple-trailer trucks operate less frequently but where values greater than 1.50 are found. For example, node 19 indicates that relative to the overall sample, on non-interstate facilities that are sloped and have a 65–75 mph speed limit, multiple-trailer trucks are 11 percent more likely than single-trailer trucks to be involved in a fatal crash.

In summary, the AID analysis indicates that multiple-trailer trucks are more likely to be involved in fatal crashes when a certain set of circumstances prevail. Lighting, road surface conditions, and multiple-vehicle crashes (implying at least moderate traffic density) play important roles in nodes with predicted values greater than 1.50.

Table 3-2. Partition of the sample on the basis of type of combination truck involved in fatal crashes



MCA Analysis

We now turn to the MCA analysis, which allows a more complete assessment of the effects of individual circumstances on crash involvement by the two different categories of combination trucks. These effects are assessed both without considering the simultaneous effects of the other independent variables and with these effects taken into account. Recall that one of the objectives of the AID analysis was to identify any notable interactions among the circumstances that would require inclusion of interaction terms in the MCA analysis, given that MCA requires additivity. Reviewing Table 3-2, no interaction effects among the predictor variables are evident to an extent such that any cross-product terms are called for.

The contributions of the respective variables to differential crash involvement are displayed in Table 3-3 in the order of their ability to explain variance in the dichotomous dependent variable. The beta coefficient indicates the sum of the squares attributable to the independent or predictor variable (holding other predictors constant) relative to the total sum of the squares. When the predictor variables are correlated (the usual circumstance), the sum of the beta coefficients typically will exceed the predictive power of the MCA equation. The most useful interpretation is that the beta coefficients reflect the relative importance of the various predictors (Andrews et al. 1967, p. 118). For purposes of signification testing, F-ratios for each predictor variable have been calculated (adjusting for the inflated sample size due to weighting). Light condition and speed limit are significant at the 0.05 level; number of vehicles involved and whether the crash occurred at an intersection are significant at the 0.10 level; and the other measures are not statistically significant. The overall model is significant at the 0.001 level.

The column labeled "Unadjusted Predicted Mean" is the mean value of the dependent variable for members of each specific variable category. For example, in our sample with almost equally-sized categories, fatal crashes occurring in conditions of darkness are 9 percent more likely to involve multiple-trailer trucks than is true of the overall sample (and thus multiple-trailer trucks are 18 percent more likely to be involved in such crashes than are single-trailer trucks). The column with the label "Adjusted Predicted Mean" presents the mean value of the dependent variable corresponding to each variable category taking into account the effects of all the other measures included in the analysis. With the other measures considered, multiple-trailer trucks are 7 percent more likely to be involved in nighttime fatal crashes than is the overall sample. (Thirty-eight percent of the fatal crashes involving multiple-trailer trucks occurred at night.) The difference is due to some of the other conditions explained by different measures that also occur at night. Note that multiple-trailer trucks are also 8 percent more likely to be involved in fatal crashes under conditions of snow, slush, or ice. Ice conditions in particular are perhaps more common at night; this factor may be one of those tempering the reduced effects of darkness and snow, slush, and ice when the influences of other measures are taken into account. It also may be the case that multiple-trailer trucks operate at night to a greater degree than single-unit trucks. If so, increased exposure would influence this difference in crash involvement.

Another important result is that compared to the overall sample, multiple-trailer trucks are 7 percent more likely to be part of fatal crashes involving three or more vehicles. Even including the effects of the other measures, multiple-trailer trucks are 6 percent more likely to be involved in such crashes. A possible explanation is that multiple-vehicle crashes are more likely when traffic volumes are comparatively high; and to the extent that double- or triple-trailer trucks are less maneuverable, they may be more likely to contribute to, or be less able to avoid, crashes in more crowded traffic conditions. Another possible explanation is that by virtue of their greater length, multiple-trailer trucks may collect more vehicles when they are involved in a crash.

Table 3-3. Predicted means related to individual variable categories

		Predicted Mean		
Name	Categories	Unadjusted	Adjusted	Beta
Light	1 Daylight	1.45	1.46	
	2 Dark but lighted	1.51	1.53	0.10
	3 Dawn or dusk	1.50	1.50	
	4 Dark	1.59	1.57	
Vehicle	1 1 Vehicle	1.48	1.46	
	2 2 Vehicles	1.49	1.50	0.07
	3 3 or more vehicles	1.57	1.56	
Speed	1 < 55 mph	1.40	1.45	
	2 55 – 60 mph	1.49	1.51	0.06
	3 65 – 75 mph	1.59	1.53	
Class	1 Interstate/Freeway	1.57	1.54	
	2 Arterial	1.44	1.47	0.06
	3 Lower standard	1.43	1.47	
Slope	1 Level	1.51	1.52	0.04
	2 Not level	1.49	1.48	
Intsn	1 Not at an intersection	1.54	1.52	0.04
	2 At or near an intersection	1.43	1.47	
Setting	1 Urban setting	1.48	1.49	0.02
	2 Rural setting	1.52	1.51	
Surface	1 Dry	1.50	1.51	
	2 Wet	1.50	1.49	0.01
	3 Snow, slush, or ice	1.58	1.51	

Multiple-trailer trucks are 9 percent more likely than is the overall sample to be involved in fatal crashes on highways with posted speed limits of 65–75 mph; when the effects of other measures are taken into account, multiple-trailer trucks are 3 percent more likely to be involved than is true of the overall sample. Note, too, that multiple-trailer trucks are considerably less likely to be involved in fatal crashes on lower-speed-limit roads (those with legal speeds of less than 55 mph). On sloped road segments, multiple-trailer trucks are also slightly less likely to be involved in fatal crashes. The other measures in the analysis do not materially alter this effect. Consistent with this result is that relative to the overall sample, multiple-trailer trucks are 7 percent more likely to be involved in fatal crashes on interstate highways or freeways, and they are 7 percent less likely to be involved in crashes on lower standard roads. These effects are diminished somewhat when the effects of other measures are considered. Quite likely, the primary influence here is that the operation of multiple-trailer trucks is concentrated on major highways, including interstates.

In a similar vein, multiple-trailer trucks are relatively more likely to be involved in fatal crashes at points other than intersections. These longer, less maneuverable trucks are incompatible with many urban streets and roads, so trucking companies are far less likely to operate them on these facilities. Also, because interstate highways and freeways have grade-separated interchanges, the sorts of highways multiple-trailer trucks operate on most frequently have comparatively few intersections and interchanges.

As noted earlier, compared to the overall sample, multiple-trailer trucks are 8 percent more likely to be involved in crashes when the road surface is covered with snow, slush, or ice. This effect dissipates when the effects of other measures are included, however. The final two measures lend only indirect insight into conditions under which multiple-trailer trucks differ from single-trailer units. Multiple-unit trucks are just slightly more likely to be involved in fatal crashes in rural areas. Yet the fact that the difference is not greater may indicate that multiple-trailer trucks have problems in urban areas. They are far less commonly operated within urban areas, so one would expect a greater difference in likelihood of involvement in a fatal crash.

Using the MCA model to predict, in conditions of darkness, a crash involving three or more vehicles (indicating at least a moderate traffic volume), a relatively high-speed highway (speed limit of 65–75 mph), an interstate highway, a level segment away from an intersection or interchange, a rural setting, and snow, slush, or ice on the road surface, the model amasses a predicted value of approximately 2.0. This implies that multiple-trailer trucks are decidedly more likely to be involved in a fatal crash with these conditions than are single-trailer trucks.

CONCLUSIONS

Our analysis of crash data from the Trucks Involved in Fatal Accidents (TIFA) data file indicates that certain conditions are associated with greater than expected (in a statistical sense) involvement by combination trucks with two or three trailers. We are cautious to note that some of the conditions are to be anticipated because they reflect those under which these trucks operate most commonly. Even so, the AID analysis shows substantial differences of up to 60 percent between the most and least likely circumstances for fatal crash involvement by multiple-trailer trucks. The additive MCA analysis corroborates these findings, showing conditions with relatively high involvement to include darkness; snow, slush, or ice on the road surface; involvement of three or more vehicles, indicating at least a moderate traffic volume; and higher-speed facilities with 65 to 75 mph limits. Overall, the MCA model predicts that under certain conditions, multiple-trailer trucks are heavily represented in fatal crashes.

Our data do not allow us to discern which of the multiple-trailer vehicles involved in fatal crashes were STAA doubles and which were LCVs. Yet even a cautious interpretation suggests that restricting LCV use when road surface conditions are not good, traffic is relatively heavy, and flow speeds are high would be prudent.

CHAPTER 4
SAFETY OF LCVS ON TWO-LANE HIGHWAYS

It certainly is the case that the vast majority of longer combination vehicle travel would occur on high-standard rural highways, particularly interstate highways. Quite likely, most of the locations served by LCVs would be quite close to these major highways. There would be many instances, however, when LCVs would need to travel to locations accessible only by two-lane highways that connect to the four-lane highways. An issue thus arises as to the safety of LCVs operating on two-lane highways as they travel to and from shipping facilities.

One of the primary safety issues related to LCVs operating on two-lane highways is the potentially greater risk posed to occupants of vehicles whose drivers wish to travel at a higher speed than LCVs and thus attempt to pass. The objective of this chapter is to assess the safety implications of circumstances likely to be encountered when LCVs operate on two-lane highways. To make this assessment, we have developed a new, more advanced vehicle-passing model. Compared to existing models, this stochastic model more accurately considers four interacting factors related to whether an overtaking maneuver on a rural two-lane highway is likely to be successful. The four factors are differences in the:

- performance levels of different classes of autos,
- aggressiveness of drivers of overtaking vehicles,
- volume and spacing of oncoming (conflicting) traffic, and
- lengths of vehicles being overtaken (impeding vehicles).

Applying this passing model, we provide estimates of the extent to which the likelihood of a successful passing maneuver will vary with the length of a combination truck being overtaken. Does the additional length of LCVs imply a greater risk to the safety of overtaking vehicles? If so, to what extent?

THE ISSUE OF LCVS ON TWO-LANE HIGHWAYS

Wang and Cartmell (1998, p. 536) found that over the last 25 years, trucks have increased in size and weight, stimulated primarily by the reduction of unit transportation costs with increased payload. Barton and Morral (1998, p. 43) reported that for low-density cargo on long hauls, LCVs could reduce highway transportation costs by as much as one-third. In a forecast of U.S. freight transportation trends, the American Trucking Associations (ATA) has projected that the trucking industry will capture about 65 percent of the ton-miles of primary freight shipped within the continental U.S. in 2008 (InsideATA 2002). According to the ATA, a major reason for the market share increase is a match between the high level of service and efficiencies of trucking and the just-in-time shipping demands of manufacturers, distributors, and retailers. The increase in freight handling is bound to lead to increased truck vehicle miles traveled (VMT) by trucks over two-lane highways. Further, the increase in market share and the efficiencies of LCVs will likely lead to an increase in demand for operating longer trucks on two-lane highways in an effort to serve more shippers.

As we noted in Chapter 3, the 21 states that presently allow combination trucks with two trailers restrict these trucks to interstate highways. It is realistic, however, to suppose that if LCVs become more commonplace, increased demand will lead states to reconsider the restrictions on the types of highways and roads LCVs can travel. Hence, we think it is prudent to evaluate the effects of LCVs on the safety of other vehicles traveling on two-lane highways, even though they rarely are permitted to do so today.

LCVs and Passing on Two-Lane Highways

Increasing LCV traffic on two-lane highways may lead to an increase in vehicle passing. Gattis et al. (1997, p. 34) and Romana (1999, p. 94) observed passing activity on two-lane highways and found that passing increases as the separation gap between the passing and impeding vehicles (those being overtaken) decreases below three seconds. Romana also observed that the speed differential between the passing and impeding vehicles decreases as the volume of traffic flow increases. The speed differential is important because as it decreases, so does the chance of successfully completing a pass. If the numbers of longer trucks mixing in the traffic stream on two-lane highways increases, and if they travel slow enough to create gaps of three second or less, vehicles attempting to pass will be at a greater risk of failing to complete the maneuver.

With increased passing activity, the number and severity of crashes generally will increase. To study the problem of passing-related crashes on two-lane rural roads, FHWA-sponsored research examined crash data from three states (FHWA 1994). The analysis showed that between 1.4 and 2.6 percent of all crashes on rural two-lane roads were related to passing. Of these crashes, the research found that sideswipe, single vehicle, and rear-end collisions were the most common types. The authors concluded that drivers go to extremes to avoid head-on collisions, thereby increasing the other collision types during failed passing maneuvers. In all three states, the percentage of fatal and incapacitating passing crashes was on average higher than that of non-passing crashes.

Predicting the success of a passing maneuver is complex because many factors play into the success of the maneuver. Some of these factors relate to the performance of the passing vehicle, driving style of the operator of the passing vehicle, volume of traffic flow in the opposing direction, and characteristics of the impeding vehicle. To simplify the task of prediction, researchers have used vehicle flow to gauge the likelihood of a successful passing maneuver. Romana (1999, p. 91) observed that passing is most effective when opposing flow rates are balanced and in the range of 500 to 800 vehicles per hour. He concluded that when flow rates fall below 500 or increase above 800 vehicles per hour, fewer than what he considered to be the theoretical maximum number of drivers tend to attempt passes. Romana attributed the less-than-optimal number of passes during low flows to the lack of desire to pass because drivers have the ability to maintain their desired speed; when flow volumes are high, drivers have too few opportunities to pass.

Kaub (1990) also investigated passing behavior on a two-lane highway. He found that at low flow (285 to 425 vehicles per hour with traffic flows split 60 to 70 percent in one direction and 30 to 40 percent in the opposite direction), drivers made 25 to 35 percent of their passes in the presence of opposing vehicles. Drivers were able to complete an average of 21 passes per hour with an average duration of 12.2 seconds at 60 mph, and they aborted 0.8 percent of the time (p. 160). At higher flows (400 to 590 vehicles per hour with splits of 83/17 to 71/29), drivers made 26 to 50 percent of their passes in the presence of opposing vehicles. There was an average of 16 passes completed per hour, with an average duration of 11.3 seconds, and drivers aborted 7 percent of the attempted passes (p. 161).

Kaub attributed the increase in passing in the presence of opposing traffic to an increase in the risk acceptance of drivers. He showed that when the opportunity to pass is 33 percent of a free-flow condition, drivers double their acceptance of risk, measured by the size of the gap in oncoming traffic when they initiate a pass. Barton and Morrall (1998, p. 46) studied passing maneuvers of autos overtaking other autos and autos overtaking 98-foot Rocky Mountain doubles. They observed that when the impeding vehicle was an auto, the passing driver accepted a 17-second gap in the opposing traffic stream on average, whereas when the impeding vehicle was a Rocky Mountain double, the average acceptable gap was 39 seconds.

Possible Traffic Volume Limits for Passing

In response to the increasing demand for LCVs on Canada's two-lane highways, Barton and Morrall (1998, p. 48) developed recommendations for the safe operation of LCVs. For two-lane highways that have 100 percent passing zones, they recommend a maximum two-way flow of 425 vehicles per hour when Rocky Mountain s are permitted and 381 vehicles per hour when either 124-foot turnpike doubles and 115-foot triple trailers are allowed. When two-lane highways have 1.25 mile passing lanes spaced every six miles, they recommend maximum two-way flows of 734 vehicles per hour for Rocky Mountain doubles and 658 vehicles per hour for turnpike doubles and triple trailers. A 30 percent net passing opportunity (defined as the product of the percentage of an hour with gaps greater than 30 seconds and the percentage of passing zones) is maintained under these recommendations. Under the stated flows, having a 30 percent passing opportunity and a traffic stream of 15 percent trucks and 3 percent recreational vehicles is equivalent to a level of service C for two-lane highways.

PREVIOUS PASSING MODELS SENSITIVE TO VEHICLE LENGTH

Many factors that we cannot directly observe contribute to the success or failure of a passing maneuver. To capture the effects of these factors, several analytic models have been developed. Two of the most cited models are those of Lieberman (1982) and Glennon (1988). Both Lieberman and Glennon evaluated the adequacy of passing sight distance standards used to define passing zones on two-lane highways. Lieberman developed a model sensitive to vehicle speed, length, and acceleration. As one would expect, he concluded that lower performing autos require a longer sight distance than do most other autos. In addition, longer sight distances are required when the impeding vehicle is a 65-foot truck than when the impeding vehicle is an auto. Based on an acceleration rate of 12 feet/second^2 for the passing vehicle, an initial speed differential of 10 mph between the passing and impeding vehicles, and an impeding vehicle speed of 55 mph, an auto requires approximately 2,350 feet to pass another auto and 2,700 feet to pass a 65-foot truck (Lieberman 1982, p. 76).

Role of Length of the Impeding Vehicle

Glennon (1988) derived a model to describe the critical position within a passing maneuver where the passing sight distance is the same whether the pass is completed or aborted. (One could term this critical position "the point of no return.") His model is based on the assumption that the opposing, impeding, and passing vehicles maintain a constant speed unless the driver aborts the pass. When the pass is aborted, the passing vehicle decelerates at 8 feet/second^2. Glennon tested the sensitivity of his model by varying the length of the impeding vehicle, and his results allow the interpolation of the effects of various vehicle lengths. Applying Glennon's model, vehicles that are equivalent to a Rocky Mountain double, triple trailer, and a turnpike double driving at 50 mph would require 1,060 feet, 1,103 feet, and 1,129 feet, respectively, for a pass to occur. In comparison to an auto, these values represent an increase in passing sight distance of 28 percent, 33 percent, and 36 percent, respectively. Based on his model and his assumption of a 1-second perception-reaction time, it would take an auto 6.8 seconds, 6.9 seconds, and 6.9 seconds, respectively, to pass the above-mentioned trucks as compared to an auto passing another auto in 6.0 seconds.

Liu and Herman (1996) extended the earlier work of Lieberman (1982) and Glennon (1988) by formulating an analytic model relating vehicle and road characteristics to passing maneuvers on two-lane roads. They found that as the speed of the impeding vehicle increases, so does the required passing sight distance for completing or aborting the pass. Liu and Herman found, however, that the distances are different for completing the pass versus aborting it. This result differs from the findings of Glennon (1988) because Liu and Herman included passing vehicle acceleration in their model. These authors also studied the effects of varying vehicle lengths on the required passing sight distance and estimated that when an auto is passing a 70-foot combination truck with a speed differential of 10 mph and a relative approach speed of the opposing vehicle of 120 mph, the passing sight distance needed to complete the pass is 2,470 feet. This is compared to the 800 feet required when an auto is passing another auto under the same conditions. When a 70-foot vehicle is passing another 70-foot vehicle under these conditions, 3,346 feet are required for the passing sight distance (Liu and Herman 1996, pp. 68–69).

Hassan et al. (1996) revised existing passing models to estimate the minimum required passing sight distance when the interaction between the passing, impeding, and opposing vehicles was considered. Their model showed that the effect of the impeding vehicle length is important. At a speed of 68 mph, the required passing sight distance for an auto passing another auto is approximately 2,034 feet, and for an auto passing an 82-foot truck, approximately 2,198 feet are needed (p. 466).

Wang and Cartmell (1998) developed a mathematical model to evaluate the safe passing sight distance which they define as the distance required by a passing vehicle to safely initiate and complete a passing maneuver. They included 11 parameters in their model of which one is the length of the impeding vehicle. Their simulation results reveal that a positive linear relationship exists between the length of the impeding vehicle and safe passing sight distance. The authors found when an auto passes another auto that is traveling at a constant speed of 52 mph and an opposing vehicle is traveling at a constant speed of 62 mph, the safe passing sight distance is 705 feet (p. 540).

Changing the length of the impeding vehicle to 82 feet while holding all others constant showed that the safe passing sight distance was approximately 970 feet. The change in impeding vehicle length increases the necessary separation between the passing and opposing vehicle by about 37 percent. After performing a sensitivity analysis, Wang and Cartmell concluded that the impeding vehicle's speed, along with the passing vehicle's initial speed and its acceleration capability, has the greatest impact on safe passing sight distance.

Evaluation of Current Models

The above models use average values for driver and vehicle performance to generate results, although these variables in reality are probabilistic. The point of occurrence, length, and frequency of passing maneuvers along a two-lane highway are also probabilistic, leading to the need to model passing maneuvers as a stochastic process. Sparks et al. (1993) estimated passing sight distance requirements based on generalized versions of models developed by Lieberman (1982) and Glennon (1988). They incorporated the inherent random nature of vehicle and driver characteristics into the passing model by conducting a discrete stochastic simulation of the passing maneuver. The model required probabilistic input parameters that the authors obtained from the literature or estimated themselves.

The results show the passing sight distance is significantly longer when passing a long truck than an auto. When the model simulates an auto overtaking another auto traveling at 56 mph, the expected value for the sight distance is 1,240 feet. In the case of an auto overtaking a 75-foot vehicle or an 82-foot vehicle traveling at 56 mph, the expected sight distances are 1,732 feet and 1,781 feet, respectively. The later figure represents a 44 percent increase in sight distance compared to when an auto is passing another auto (Sparks et al. 1993, p. 278).

A NEW PASSING MODEL

Our review of existing models reveals that the distance a passing vehicle travels in the opposing lane of traffic increases substantially with longer impeding vehicles, compared to when the impeding vehicle is an auto. Not directly included in the models we reviewed are the effects of variable gaps in the opposing traffic stream, the congestion effects of the impeding vehicle, and the mix of overtaking vehicle performance and driving styles of operators on the successfulness of passing maneuvers. We contend that deeper insight into the safety of passing maneuvers can be obtained using a Monte Carlo stochastic model that includes less common as well as more typical situations.

We developed an agent-based stochastic simulation model to measure the effect on passing maneuvers of systematically varying the length and speed of an impeding vehicle, the flow rate of opposing vehicles, and the queuing behind an impeding vehicle. Our model builds on the logic of existing passing models of Lieberman (1982), Glennon (1988), Sparks et al. (1993), Wang and Cartmell (1998), and Yang and Koutsopoulos (1996). We also have benefited from the insight obtained in the field studies of Barton and Morrall (1998), Gattis et al. (1997), Kaub (1990), and Romana (1999).

Characteristics of Passing Vehicles and Their Drivers

Our approach is a significant enhancement over existing models in that the full range of passing behavior is explicitly modeled. The inclusion of actual vehicle capacities allows the model to estimate passing maneuvers using realistic vehicle responses. This is an advancement over the current models that use average vehicle passing distance or duration because these average values suppress the actual variation in vehicle responsiveness. Likewise, driver characteristics are modeled to reflect the diversity in driver behavior during the passing maneuver.

The base of the model has two streams of vehicles that traverse a road segment in opposite directions. Vehicle types are randomly drawn from a distribution of vehicles in use derived from the American Automobile Manufacturers Association (AAMA 1993, 1995, 1997, 2000). The mix of vehicle types—small, medium, large, and other—for the year 1999 is represented in Table 4-1. Each vehicle stream is composed of individual vehicles that possess the characteristics of length, maximum velocity, and acceleration and deceleration rates derived from published vehicle performance road tests. Based on the univariate statistics for length, maximum velocity, maximum acceleration, and maximum deceleration, we judged that normal distributions are appropriate to use. Table 4-1 presents the lengths and maximum velocities attainable for each of the four categories of vehicles, and Table 4-2 shows the maximum acceleration and deceleration capabilities of these classes of vehicles.

Not only do vehicle classes differ in their performance capabilities, the drivers of these vehicles vary considerably as well in terms of their driving styles. Four groups of drivers are shown in Table 4-3. The groups vary in terms of desired speed above the posted speed limit (see FHWA 1980); an acceptable gap behind the impeding vehicle; and for passing, an acceptable separation distance from the opposing vehicle to begin a passing maneuver.

Table 4-1. Overtaking vehicle length and maximum velocity

Vehicle type (percent of total fleet)		Vehicle length (feet)			Maximum velocity (mph)		
		Mean	Median	Std. dev.	Mean	Median	Std. dev.
Small	(33)	14.3	14.4	0.4	112	115	11
Medium	(45)	15.7	15.6	0.7	125	126	11
Large	(10)	17.2	17.2	0.6	130	133	23
Other	(12)	15.5	15.5	1.3	123	133	16

Table 4-2. Overtaking vehicle acceleration and deceleration

Vehicle type	Maximum acceleration (mph/second)						Maximum deceleration (mph/second)		
	0 to 60 mph			60 to 100 mph			100 to 0 mph		
	Mean	Median	Std. dev.	Mean	Median	Std. dev.	Mean	Median	Std. dev.
Small	6.8	6.7	0.7	2.1	2.0	0.5	39.5	39.1	3.2
Medium	7.8	7.8	0.9	2.9	2.8	0.7	39.5	39.1	3.2
Large	8.5	8.4	0.5	3.4	3.4	0.4	39.5	39.1	3.2
Other	9.7	9.9	1.6	4.4	4.5	1.3	39.5	39.1	3.2

Behavior Modeled

In the model, the lead vehicle of the passing stream acts as a constraint to the flow of the other vehicles. The impeding vehicle is assumed to maintain a constant velocity throughout the passing maneuver. Speeds of the remaining vehicles in the passing stream are assumed to be consistent with the auto-following logic outlined by Yang and Koutsopoulos (1996). This allows the passing vehicle to queue behind the impeding vehicle while waiting for its chance to begin a passing maneuver.

A passing maneuver begins when the first vehicle waiting to pass encounters an acceptable gap in the opposing vehicle stream (see Table 4-3). We use an exponential distribution to assign the separation distance between opposing vehicles to meet a specified flow. This approximates platooning (grouping) behavior of vehicles on a two-lane highway (Gattis et al. 1997). When an acceptable gap is present, the passing vehicle moves into the opposing lane and begins to accelerate from the velocity at which it was approaching (or if queued behind the impeding vehicle, its following speed). Flying passes (those when the overtaking vehicle need not decelerate when approaching the impeding vehicle) are possible.

Table 4-3. Overtaking driver characteristics

Driving style in overtaking vehicle	Assumed percentage of driving styles	Desired speed above speed limit (mph)	Acceptable following gap (seconds)	Acceptable gap in opposing traffic stream to begin pass (seconds)	
				55 mph	65 mph
Highly cautious	5	0	5	14.9	12.6
Cautious	25	5	4	13.6	11.5
Average	45	10	3	12.4	10.5
Aggressive	20	15	2	11.8	10.0
Highly aggressive	5	20	1	11.8	10.0

The passing vehicle continues to accelerate until it completes the pass, achieves its maximum velocity, or its driver elects to abort the maneuver. A completed pass occurs when the passing vehicle returns to its original lane at a predefined distance in front of the impeding vehicle. The fixed distance is 15 feet, which is the expected value used by Sparks et al. (1993). During the passing maneuver, the driver can elect to abort the pass and return behind the impeding vehicle. The model records a passing attempt as a failure when it collides with an opposing vehicle or successfully aborts the pass.

Application of the Model

We ran 64 different scenarios that varied in terms of the posted speed limit, the impeding vehicle's speed and length, and the flow rate of opposing vehicles. Table 4-4 lists the system parameters we used to define each scenario. We based our simulations on a posted speed limit of 55 mph to replicate a typical speed limit for rural two-lane highways when passing maneuvers are allowed. The selection of impeding vehicle speed of 56.5 mph is based on the average flow speed of two-lane highways in the U.S. with 55 mph speed limits (FHWA 1993). The remaining impeding vehicle speeds were selected based on previous studies in the literature; they represent realistic speeds that a combination truck might travel on a two-lane highway under different traffic conditions. A one-mile, straight, and dry road segment with 100 percent passing zones was modeled.

Table 4-4. Simulation scenarios

Measure	Parameter values tested
Posted speed limit (mph)	55
Impeding vehicle speed (mph)	48.0, 50.0, 52.5, and 56.5
Impeding vehicle length (feet)	15, 65, 100, and 120
Average opposing vehicle gap (seconds)	8.5, 11.6, 17.1, and 34.3

Lengths of the impeding vehicles are intended to represent typical vehicles of various classifications. As Table 4-1 indicates, 15 feet is a typical length of autos in the U.S. A standard single-trailer combination truck has a length of approximately 65 feet; a relatively long Rocky Mountain double is about 100 feet long, as is a comparatively short triple-trailer unit; and a turnpike double is approximately 120 feet long (see Figure 3-1).

The four opposing traffic gap intervals in opposing traffic are based on volumes of 105, 210, 310, and 425 vehicles per hour. These flow rates are comparable to those identified by Kaub (1990) and Romana (1999) in their analyses of passing on two-lane highways. In each case, the traffic distributions are assumed to be exponential, meaning that the preponderance of vehicles are essentially even in their spacing on the highway, but a smaller number are more widely spaced.

Each scenario was run 2,500 times producing distributions for selected system variables. In our simulations, the distribution of performance capabilities of passing autos and of driver characteristics are those shown in Tables 4-2 and 4-3. We chose the number of runs based on a stability analysis of the output of the model. For this study, the model recorded distributions of the time to complete a passing maneuver, the distance traveled by the passing vehicle, the average speed during the pass, and the average gap of opposing and passing vehicle streams during the simulation runs.

Figures 4-1 and 4-2 illustrate the extremes of the scenarios that we ran. Figure 4-1, which represents the highest opposing vehicle flow (an opposing vehicle gap of 8.5 seconds), clearly illustrates two passing groups. The first group, as it overtakes a 65-foot impeding vehicle that is traveling at 48.0 mph on a road with a posted 55 mph speed limit, is able to complete the passing maneuver in an average of 4.5 seconds and the second group in 7.3 seconds. A similar grouping occurs when a 120-foot vehicle is impeding flow under the same conditions. In that case, the first group overtakes in 5.5 seconds on average and the second group in an average of 8.3 seconds. The model reveals that the majority of the vehicles in the first group are those that can make flying passes.

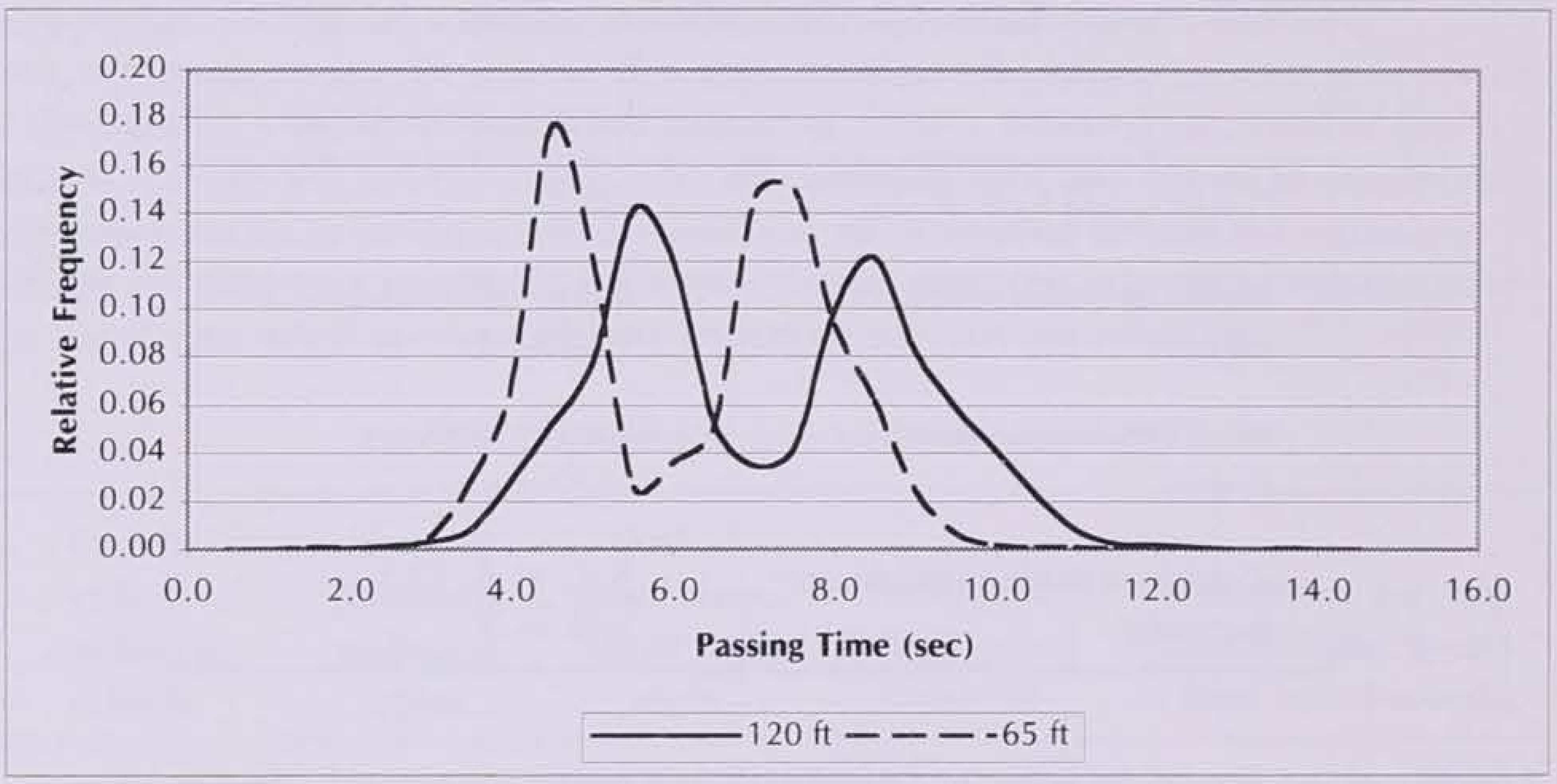


Figure 4-1. Passing time distributions with an average opposing gap of 8.5 seconds and an impeding vehicle speed of 48 mph

In Figure 4-2, we show a much less restrictive circumstance—a low opposing vehicle flow (an opposing vehicle gap of 34.3 seconds). While there still are two peaks in the time required to complete a pass of both the 65-foot and the 120-foot vehicles, the preponderance of passes are flying passes. The largest group, as it overtakes a 65-foot impeding vehicle that is traveling at 56.5 mph on a road with a posted 55 mph speed limit, is able to complete the passing maneuver in an average of 5.0 seconds. The same amount of time is required when a 120-foot vehicle is impeding flow under the same conditions. The model reveals that the vast majority of the vehicles can make flying passes when the opposing traffic volume is very low, producing large gaps in the opposing traffic.

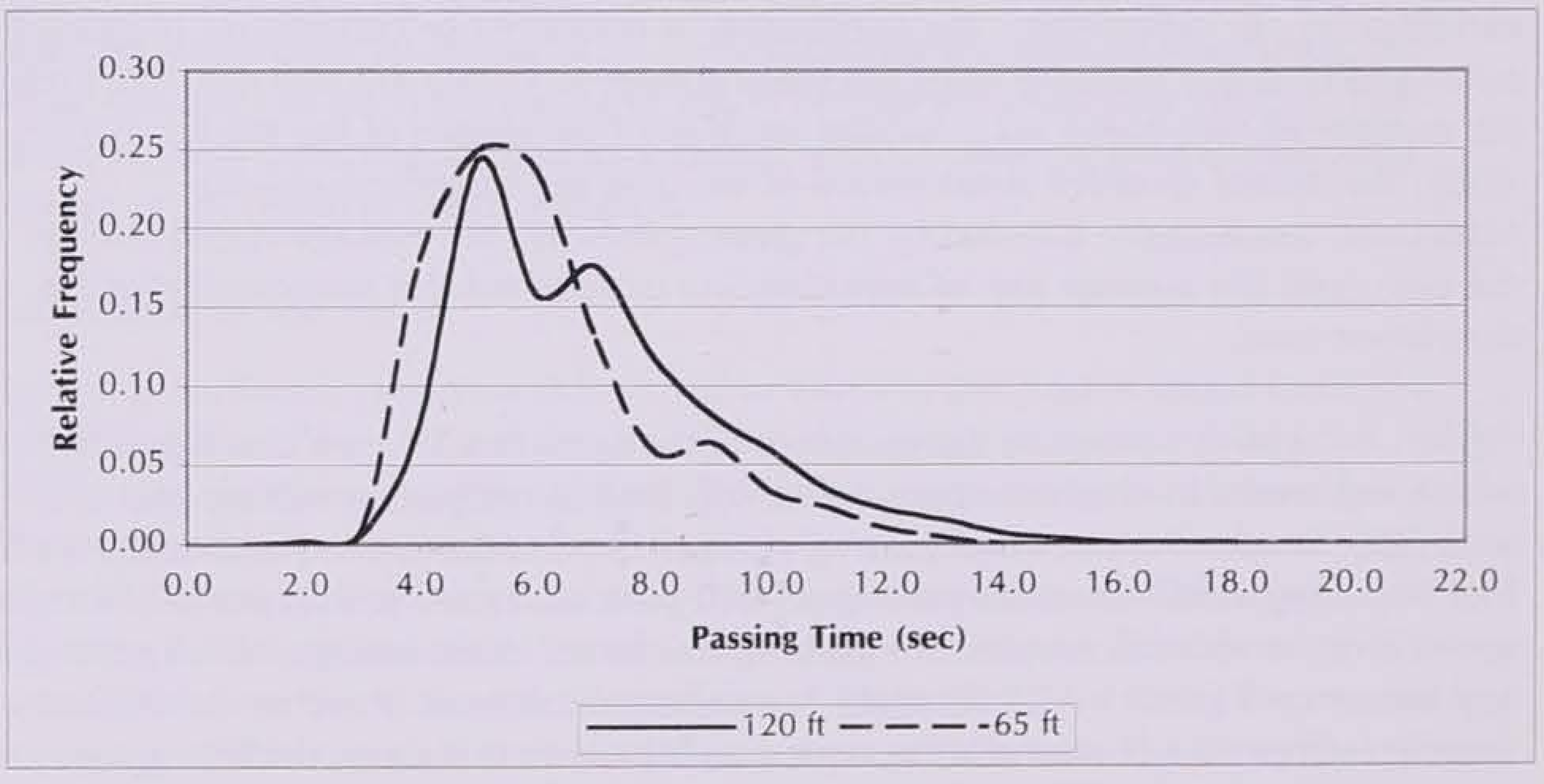


Figure 4-2. Passing time distributions with an average opposing gap of 34.3 seconds and an impeding vehicle speed of 56.5 mph

The majority of vehicles in the second group began the passing maneuver with the same speed as the impeding vehicle because the passing vehicles were queued behind the impeding vehicle, thus needing more time to accelerate and complete the maneuver. In comparison to a light opposing flow that does not cause many vehicles to queue behind the impeding vehicle, the grouping behavior as shown in the more congested scenario is not as pronounced and is shown in Figure 4-2. The conclusion drawn by the comparison is that characteristics of the passing vehicle become more significant with increasing congestion—as congestion increases, more vehicles are exposed to risk in the opposing lane for longer periods. For further comparisons of the scenarios, the mean passing time, distance, and speed were estimated as well as the percentage of completed passes.

Results of the model indicate that as the gap in opposing traffic increases, the time required to complete the passing maneuver decreases. Unlike the passing model of Glennon (1988) and Wang and Cartmell (1998), the results are not linear functions. This is because of the interdependency of the model input distributions, a feature that needed further exploration according to Sparks et al. (1993). From the figures, the exposure time in the opposing lane increases with impeding vehicle length and traffic flow speed. The most dangerous situation is shown to be a 120-foot vehicle traveling at 56.5 mph, the national average speed for two-lane highways with posted 55-mph speed limits.

The results as shown in Tables 4-5 and 4-6 reveal that the average speed of the passing vehicle increases as the impeding vehicle's speed and length and opposing flow increase. The increase in the average speed of the passing vehicle reflects the shortening of the time window caused by the decreasing gaps between opposing vehicles. From a safety perspective, combining the passing vehicle's higher speed and longer exposure time in the opposing lane will heighten both the probability and severity of passing-related crashes.

Table 4-5. Mean passing speeds to overtake vehicles of various lengths traveling at 56.5 mph

Impeding vehicle length (feet)	Opposing gap (seconds) 8.5	11.6	17.1	34.3
15	69.8	70.4	71.6	73.3
65	72.9	73.5	74.8	76.7
100	74.6	75.0	76.5	78.6
120	75.5	75.9	77.3	79.7

The model also reveals that the average speed of a passing vehicle increases with greater gaps in opposing traffic. This is because many passing vehicles face adequate gaps in the opposing flow; so as they approach the impeding vehicle. they do not have to decrease their speed (i.e., they can make flying passes). Rather, as the gaps in the opposing stream become wider, the passing vehicle begins the passing maneuver at the driver's desired speed and accelerates through the maneuver until it is completed or the vehicle's maximum speed is achieved.

Table 4-6. Mean passing speeds to overtake a 120-foot vehicle traveling at various speeds

Impeding vehicle speed (mph)	Opposing gap (seconds) 8.5	8.5	8.5	8.5
48.0	69.5	70.6	72.4	75.5
50.0	71.1	71.9	73.5	76.6
52.5	66.8	73.4	75.0	77.8
56.5	75.5	75.9	77.3	79.7

We tracked the number of failed passing attempts for each scenario. A failed passing maneuver was defined as either a successfully aborted pass or when a passing vehicle crashes into an opposing vehicle. The results are presented in Tables 4-7 and 4-8. Table 4-7 shows that attempting to pass a 120-foot impeding vehicle when there are short gaps (8.5 seconds) in opposing traffic produces a high failure rate of 50.6 percent. This compares with the failure rate when passing an auto under the same opposing traffic conditions, 10.7 percent. Even at lower opposing traffic volumes (i.e., wider gaps), the percent of failed passing maneuvers is appreciably higher for longer impeding vehicles.

Table 4-8 indicates that when the impeding vehicle is 120 feet in length, its speed is important, especially when a small gap in opposing traffic is present. Twenty percent more of the attempted passes fail when the impeding vehicle is traveling at 56.5 mph than when its speed is 48 mph. At larger gaps in opposing traffic, the role of impeding vehicle speed is diminished, but it still is important.

Table 4-7. Percent failure of passing maneuvers while overtaking vehicles traveling at 56.5 mph

Impeding vehicle length (feet)	Opposing gap (seconds) 8.5	11.6	17.1	34.3
15	10.7	8.9	4.7	1.0
65	32.1	23.1	14.7	4.8
100	44.1	33.7	21.2	8.8
120	50.6	39.1	25.3	10.8

Table 4-8. Percent failure of passing maneuvers while overtaking a 120-foot vehicle

Impeding vehicle speed (mph)	Opposing gap (seconds) 8.5	11.6	17.1	34.3
48.0	30.5	22.5	14.6	5.3
50.0	35.0	25.9	17.3	6.5
52.5	39.7	30.3	20.6	8.3
56.5	50.6	39.1	25.3	10.8

CONCLUSIONS

The analysis in this chapter is an attempt to provide as accurate an estimate as possible of the extent to which a safety problem would emerge if LCVs were to operate on two-lane highways. Among the most significant safety issues is likely to be attempts by other vehicles to pass LCVs, due to their greater length. To provide accurate estimates of likely changes in the percentage of passing attempts that result in crashes or other safety problems, we have developed an enhanced passing model.

Notable enhancements in the model include explicit consideration of different types of vehicles that may overtake LCVs on two-lane highways. The various vehicle types differ in length, acceleration and braking capabilities, and maximum velocities. Another enhancement is consideration of differences in the driving styles of people operating the vehicles that would share two-lane highways with LCVs. The varying degree of aggressiveness manifests itself in terms of the desired speed above the posted speed limit, the acceptable space behind the impeding vehicle, and the acceptable gap in the opposing traffic stream to initiate a pass.

Our model enables the assumed proportions of vehicle types and driving behavior to occur randomly among those attempting to pass impeding vehicles. It also allows traffic volumes and, hence, vehicle spacing of opposing traffic to be varied. Most germane to this research, we are able to vary the speeds and lengths of impeding vehicles.

Applying the passing model, we compare the passing time distributions when the impeding vehicle lengths are 65 feet, 100 feet, and 120 feet. These lengths represent a standard single-trailer combination truck and two types of LCVs. Our results indicate that:

- Mean passing speeds of vehicles overtaking a 120-foot LCV are approximately 3 mph higher than when the impeding vehicle is a 65-foot combination truck.

- Regarding traffic volumes, an interaction is present between the length of the impeding vehicle and the gap length in opposing traffic. With a relatively short gap of 8.5 seconds, half of the attempts to pass a 120-foot LCV fail compared to a third of the attempts to pass a 65-foot truck. At a larger gap, 34.3 seconds, the importance of impeding vehicle length on failed passing attempts is less substantial.
- The speed of the impeding vehicle also is important. If the impeding vehicle is a 120-foot LCV traveling at 56.5 mph and the opposing vehicle gap is 8.5 seconds, the percent of passing attempts that fail is 50 percent. With the same gap, but if the impeding vehicle is traveling at 48 mph, 30 percent of the passing attempts fail.

In conclusion, on two-lane highways with at least moderate traffic volumes moving at the national average flow speed on highways with speed limits of 55 mph, passing LCVs involves two safety-related problems. First, overtaking vehicles typically attain higher speeds during the passing maneuver; and, second, the percentage of passing attempts that are aborted or result in a crash is appreciably greater for LCVs than for standard combination trucks.

If fewer restrictions are placed on LCVs operating on major highways, it is very likely to be necessary for these vehicles to also operate on two-lane highways. Should this be the case, our analysis suggests that LCV travel on two-lane highways should be restricted to conditions under which traffic volumes are quite low. More precisely, the lengths of LCVs allowed on a given two-lane highway should be related to the volume of traffic prevailing on that highway.

Finally, we conclude that passing longer LCVs, those 120 feet in length or more, involves comparatively greater risk to overtaking vehicles, especially when flow speeds are relatively high. In the interest of safety, the allowable length of LCVs that may operate on various two-lane highways should be evaluated carefully.

CHAPTER 5
CONCLUSIONS AND POLICY IMPLICATIONS

We estimated the intercity freight transportation costs related to crashes and accidents in Chapter 2. In Chapter 3, we focused on the relative propensity of multiple-trailer freight trucks to be involved in fatal crashes, and in Chapter 4 we examined the issue of passing LCVs on two-lane highways. Some assumptions have been necessary to carry out these analyses, and some of our conclusions depend on a careful interpretation of earlier research by others. We first recap the roles of these assumptions and the antecedent research, and then we highlight our conclusions and several policy implications of these conclusions.

ASSUMPTIONS AND QUALIFICATIONS

The unit of our comparative analysis of crash costs is the ton-mile. In Chapters 2 and 3, we observe that this is an imperfect unit of measurement for comparing the social costs of freight trucking and rail. For one thing, there are no precise data on the ton-miles of freight shipped by either mode—it would be difficult to maintain accurate records for each shipment completed in the nation, so the figures available are only approximations. More important, the nature of operations of the two transportation modes is sufficiently different that essentially any unit of service delivery is certain to be flawed. Regarding safety, as we noted earlier, trucks operate on public roadways where they have a much higher exposure to crashes than generally is true of freight rail. Further, trucks carry a comparatively small number of tons of freight per trip, so many more trucks must operate to produce a given number of ton-miles. All of this said, the ton-mile remains the best possible unit of measurement for comparing freight modes, and it is especially appropriate for examining the approximately 664.9 billion ton-miles annually that are competitive between the two modes.

An important social cost for both rail and truck freight transportation stems from crashes and accidents. To carry out our analyses of the relative costs to society of these two freight modes, we have had to make several key assumptions including the values assigned to fatal and personal injury accidents. There is only limited consensus on the appropriate values to use for transportation-related mishaps. In a survey of all 50 state departments of transportation conducted in 1993, we found they were using an average value of $1.2 million for fatalities and $41,000 for injuries (Forkenbrock et al. 1994, p. 18). The U.S. DOT has requested that we use a value of $3 million per fatality because that is the value now used in its safety analyses. We should note that this is a fairly conservative figure; studies of the health effects of environmental pollution often use higher values. For example, a decade ago Hall et al. (1992, p. 815) found that recommended values range from $4.0 million to $9.2 million for the worth to society of saving a statistical life. When interpreting our results, one must recognize that such valuation is by nature normative and imprecise. The best use of our analysis is to compare the relative safety of the two freight modes.

Our analysis of circumstances surrounding fatal crashes involving multiple-trailer combination trucks can provide useful contrasts with single-trailer combination trucks, but it can only provide limited insights into the crash involvement of LCVs. The data file we used does not distinguish between shorter multiple-trailer trucks (i.e., STAA doubles), which are legal nationwide, and longer and heavier multiple-trailer trucks whose use is more restricted. In effect, our analysis is quite conservative in that many, perhaps most, of the fatal crashes involving multiple-trailer trucks in the data file do not involve the longer two- and three-trailer units that are of greatest concern in an analysis of the relative safety of LCVs. Yet, our analysis does provide insights into the conditions under which multiple-trailer trucks in general have demonstrated a greater propensity to be involved in fatal crashes. How much more the differences in crash experiences would be between multiple- and single-trailer trucks if the former were strictly LCVs is unclear, but it is not unreasonable to suppose that these differences would be greater.

KEY FINDINGS

The analyses reported in the foregoing chapters have produced a series of insights that are germane to transportation policy. Our key findings are:

- A major social cost imposed by truck or rail freight transportation pertains to safety. In 2000, combination trucks were involved in 3,708 fatal crashes, 50,000 personal injury crashes, and 171,000 property-damage-only crashes. The overall cost to society of these crashes was $18.3 billion. On a per-ton-mile basis, the cost was slightly less than one cent. In 2000, 3,446 passenger vehicle occupants died in crashes with large trucks of all sorts, while 534 occupants of these trucks were killed.
- A total of 647 persons were killed in accidents involving Class I freight rail during 2000, and 6,243 persons were injured. The social cost of these mishaps was about $2.3 billion, and the cost per ton-mile was approximately two-tenths of a cent. Thus, the societal cost per ton-mile in 2000 for freight trucking was about 5.6 times greater than for freight rail.
- We examined the conditions under which two- or three-trailer combination trucks are more likely to be involved in fatal crashes than are single-trailer combination trucks. These conditions include: darkness; snow, slush, or ice on the road surface; involvement of three or more vehicles, indicating at least a moderate traffic volume; and higher-speed facilities with 65 to 75 mph limits. We acknowledge that some of these conditions very likely reflect those under which multiple-trailer trucks operate most frequently.

- On two-lane highways with at least moderate traffic volumes moving at the national average flow speed on highways with speed limits of 55 mph, passing LCVs involves two safety-related problems. First, overtaking vehicles typically attain higher speeds during the passing maneuver; and, second, the percentage of passing attempts that are aborted or result in a crash is appreciably greater when impeding vehicles are LCVs than is the case with standard combination trucks.

The conclusion of this research is that even when using conservative values for social costs, these costs are sizable enough to warrant concern. Costs due to crashes affect the well-being of society and should be fully included in the decision-making process of how much service by each transportation mode should be consumed. Our research has sought to provide reasonable estimates of the extent to which intercity truck and rail transportation affect the safety of society. We hope that these estimates will help facilitate enlightened public and private sector decision-making regarding facility investment, regulation, and pricing.

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