FINAL REPORT

THE PRODUCTIVITY EFFECTS OF TRUCK SIZE AND WEIGHT POLICIES

David P. Middendorf
Michael S. Bronzini
Center for Transportation Analysis
Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

November 1994

Managed by
Martin Marietta Energy Systems, Inc.
for the
Department of Energy
under Contract No. DE-AC05-84OR21400

Prepared for
Federal Highway Administration
U.S. Department of Transportation
Washington, D.C. 20590

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

<u>Chapter</u>	<u>Page</u>
EXECUTIVE SUMMARY	xv
1. INTRODUCTION	1
BACKGROUND	1
RESEARCH OBJECTIVES	1
ORGANIZATION OF THE REPORT	2
2. DATA COLLECTION AND LOGISTICS COST ANALYSIS METHODOLOGY	5
INTRODUCTION	5
SHIPPER SURVEY	5
Information Collected	5
Data Collection Methodology	7
Sample Size and Characteristics	10
FREIGHT TRANSPORTATION ANALYZER	13
3. EFFECTS OF LCV USAGE ON THE LOGISTICS COSTS OF TRUCK SHIPPERS	19
INTRODUCTION	19
OVERALL EFFECTS	19
INFLUENCE OF VARIOUS COST, PRODUCT, AND LANE VARIABLES	22
Ratio of Freight to Inventory Costs	22
Product Value	25
Annual Lane Volume	26
Lane Distance	29
Annual Lane Ton-Mileage	29
Product Value and Annual Lane Volume	31
Product Value and Annual Lane Ton-Mileage	37
INTRAMODAL DIVERSION TO LCVs	38
4. EFFECTS OF LCV USAGE ON THE LOGISTICS COSTS OF RAIL AND INTERMODAL SHIPPERS	45
INTRODUCTION	45
RAIL BOXCAR SHIPPERS	45
INTERMODAL SHIPPERS	51
5. ESTIMATION OF NATIONWIDE LCV USAGE	59
INTRODUCTION	59
INTRAMODAL DIVERSION MODEL	59
ESTIMATION PROCEDURE	60

TABLE OF CONTENTS (Continued)

<u>Chapter</u>	<u>Page</u>
5. ESTIMATION OF NATIONWIDE LCV USAGE (continued)	
ESTIMATED INTRAMODAL DIVERSION	66
COMPARISON WITH OTHER ESTIMATES	71
6. CONCLUSIONS	75
REFERENCES	79

LIST OF FIGURES

<u>Figure No.</u>	<u>Page</u>
1. Percent reduction in total logistics cost using LCVs under low GVW limits as a function of freight to inventory cost ratio for single trailers	23
2. Percent reduction in total logistics cost using LCVs under high GVW limits as a function of freight to inventory cost ratio for single trailers	24
3. Rail freight rate versus percent cost reduction using Rocky Mountain doubles under existing GVW limits	47
4. Rail freight rate versus percent cost reduction using Rocky Mountain doubles under higher GVW limits	48
5. Rail freight rate versus percent cost reduction using turnpike doubles under existing GVW limits	49
6. Rail freight rate versus percent cost reduction using turnpike doubles under higher GVW limits	50
7. Intermodal freight rate versus percent cost reduction using Rocky Mountain doubles under existing GVW limits	54
8. Intermodal freight rate versus percent cost reduction using Rocky Mountain doubles under higher GVW limits	55
9. Intermodal freight rate versus percent cost reduction using turnpike doubles under existing GVW limits	56
10. Intermodal freight rate versus percent cost reduction using turnpike doubles under higher GVW limits	57

LIST OF TABLES

<u>Table No.</u>	<u>Page</u>
1. Distribution of traffic lane observations in the shipper survey by type of product	11
2. Distribution of traffic lane observations in the shipper survey by mode of transportation and type of equipment	12
3. Weight capacity of longer combination vehicles under two gross vehicle weight (GVW) limit scenarios	14
4. Cubic capacity of longer combination vehicles compared to single trailers of various sizes	15
5. LCV rate adjustment factors based on a comparison of operating costs per loaded mile	16
6. Breakdown of FTA observations by current principal mode	17
7. Overall effect of LCVs on the total logistics cost of single trailer truck shippers by type of LCV, GVW limits, and relative LCV rates	20
8. Truck configuration resulting in the lowest total logistics cost by GVW limits and relative LCV rates	21
9. Correlation between product value and the percent reduction in total logistics cost resulting from LCV usage	26
10. Correlation between percent cost reduction from using LCVs and the composite variable formed by multiplying product value by the inventory carrying cost expressed as a percentage of inventory value	27
11. Average percent reduction in total logistics cost from use of LCVs for different levels of annual lane volume	28
12. Correlation between annual lane volume and the percent reduction in total logistics cost resulting from LCV usage	29
13. Average percent reduction in total logistics cost from use of LCVs for different traffic lane distances	30

LIST OF TABLES (continued)

<u>Table No.</u>	<u>Page</u>
14. Average percent reduction in total logistics cost from use of LCVs for different levels of annual lane ton-mileage	31
15. Correlation between annual lane ton-mileage and the percent reduction in total logistics cost resulting from LCV usage	32
16. Combined effect of annual lane volume and product value on total logistics cost using Rocky Mountain doubles under existing GVW limits	33
17. Combined effect of annual lane volume and product value on total logistics cost using Rocky Mountain doubles under higher GVW limits	34
18. Combined effect of annual lane volume and product value on total logistics cost using turnpike doubles under existing GVW limits	35
19. Combined effect of annual lane volume and product value on total logistics cost using turnpike doubles under higher GVW limits	36
20. Combined effect of annual lane ton-mileage and product value on total logistics cost using Rocky Mountain doubles under existing GVW limits	39
21. Combined effect of annual lane ton-mileage and product value on total logistics cost using Rocky Mountain doubles under higher GVW limits	40
22. Combined effect of annual lane ton-mileage and product value on total logistics cost using turnpike doubles under existing GVW limits	41
23. Combined effect of annual lane ton-mileage and product value on total logistics cost using turnpike doubles under higher GVW limits	42
24. Percent of FTA cases and ton-mileage assumed to divert to LCVs under different GVW limits, cost savings thresholds, and relative LCV freight rates . .	43
25. Overall effect of LCVs on the total logistics cost of rail boxcar shippers	46
26. Transportation mode with the lowest total logistics cost for rail boxcar shippers	46

LIST OF TABLES (continued)

<u>Table No.</u>	<u>Page</u>
27. Correlation between rail freight charge per mile and percent reduction in total logistics cost from switching to LCVs	51
28. Overall effect of LCVs on the total logistics cost of intermodal shippers	52
29. Transportation mode with the lowest total logistics cost for intermodal shippers	53
30. Correlation between intermodal freight charge per mile and percent reduction in total logistics cost using LCVs	53
31. Percent of annual traffic lane ton-mileage that would divert to LCVs	61
32. Definitions of relevant data items selected from 1987 TIUS public use records	63
33. Estimated truck vehicle-miles (in millions) diverting to LCVs under existing GVW limits with LCV freight rates same as current single trailer truckload rates	67
34. Estimated truck vehicle-miles (in millions) diverting to LCVs under existing GVW limits with LCV freight rates higher than current single trailer truckload rates	68
35. Estimated truck vehicle-miles (in millions) diverting to LCVs under higher GVW limits with LCV freight rates same as current single trailer truckload rates	69
36. Estimated truck vehicle-miles (in millions) diverting to LCVs under higher GVW limits with LCV freight rates higher than current single trailer truckload rates	70
37. Estimated billions of truck miles diverting to Turner prototypes in the intercity dry van truckload market sectors	73

LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
CFS	Commodity Flow Survey
cwt	hundredweight (hundreds of pounds)
EOQ	economic order quantity
FAK	freight all kinds
FTA	Freight Transportation Analyzer computer program
GVW	gross vehicle weight
LCV	longer combination vehicle
LTL	less than truckload
SIC	Standard Industrial Classification
TIUS	Truck Inventory and Use Survey
TOFC/COFC	trailer-on-flatcar/container-on-flatcar
TRB	Transportation Research Board

ACKNOWLEDGEMENTS

The authors are grateful to the Center for Logistics Research at The Pennsylvania State University, which conducted the shipper survey and ran the Freight Transportation Analyzer (FTA) computer program. The results of the survey and the FTA program provided the data for the research described in this report. In particular, the authors would like to thank Mr. Paul Poissant and Ms. Rosemarie Greaser for compiling and editing the data from the shipper survey and the output from the FTA; Dr. Gary L. Gittings, Assistant Professor of Business Logistics, for providing technical assistance and a description of the survey methodology; and Dr. Alan J. Stenger, Associate Director of the Center for Logistics Research, for granting permission to use his FTA model for this study.

The authors are also grateful to the Federal Highway Administration, which sponsored the research described in this report, and in particular, Mr. Jake Jacoby for his valuable technical guidance.

EXECUTIVE SUMMARY

While previous studies have indicated that increases in truck size and weight limits could improve motor carrier productivity, the question of whether or not freight shippers will also benefit has not been adequately addressed. It is generally assumed that competitive conditions in the motor carrier industry will result in cost savings being passed to shippers in the form of lower freight rates. Transportation costs, however, are only one component of shipper total logistics cost. Warehousing cost, inventory holding cost, order processing cost, and other categories of business logistics cost may also change as a result of the less frequent but larger shipments typically associated with the use of longer combination vehicles (LCVs). If switching from single trailer truckload shipments to LCVs causes shipper non-transport logistics costs to increase more than the savings available from lower freight rates, then productivity gains may be lost to the firm and the economy as a whole. This research was undertaken to determine the net effect of truck size and weight policy changes on shipper total logistics cost and how these effects might influence the demand for alternative tractor-trailer configurations.

One of the more difficult tasks in this study was the collection of logistics cost data on which to perform the analysis. Original data of a highly confidential nature was required to fulfill the study's objectives. Firms are naturally reluctant to divulge sensitive data which might compromise their competitive position. Many of the firms contacted in this study were willing to provide freight flow data for their principal products; however, even when assured of confidentiality, they frequently remained either unwilling or unable to specify critical logistics costs such as order processing cost and inventory carrying cost. Some of the contacted firms also lacked the sophisticated logistics management systems necessary to respond fully to the detailed questions that were asked. As a result, this research is based on a limited sample of 297 product-specific traffic lane (origin-destination) movements obtained from a total of 72 companies.

The data on product characteristics, lane volumes, transportation cost, and other logistics costs gathered in the shipper survey were entered into a computer program called the Freight Transportation Analyzer (FTA). Developed by Dr. Alan J. Stenger of the Pennsylvania State University Department of Business Logistics, the FTA implements a deterministic economic order quantity (EOQ) model adapted to incorporate transportation costs. For each lane observation in the survey dataset, the FTA calculated the shipper's annual freight, order, and inventory carrying costs for the shipper's current mode of transport as well as for two types of LCVs: the Rocky Mountain double combination consisting of a tractor pulling a 48-ft (14.6-m) trailer followed by a 28-ft (8.5-m) trailer and the turnpike double combination which is a tractor pulling two 48-ft (14.6-m) trailers.

A major finding of the study is that, in most cases, use of LCVs would have a significant favorable impact on the annual total logistics cost of truckload shippers. Savings in annual total logistics cost as high as 59 percent for turnpike doubles and 52 percent for

Rocky Mountain doubles were observed. Average savings depend on the type of LCV used, gross vehicle weight (GVW) limits, and the difference between the rates charged by motor carriers for LCV and single trailer transport. For example, the study predicted average savings of 32 percent for shippers switching to turnpike doubles operating at 131,000-lb (59,422-kg) GVW limits under LCV freight rates that are the same as current single trailer freight rates. The average savings drop to 21 percent when turnpike double freight charges are 30 percent higher than current single trailer freight rates.

The greater the flow of a company's product in the lane and the longer the lane, the more likely it is that a shipper would benefit from using some type of LCV. When annual lane volumes are below 5000 cwt (226,795 kg), LCVs tend to increase the shipper's annual total logistics cost. When annual lane volumes exceed 25,000 cwt (1,133,975 kg), however, LCVs nearly always produce significant cost savings.

An excellent indicator of whether or not a truckload shipper would benefit from switching to LCVs is the ratio of the shipper's current annual single trailer freight costs to annual inventory carrying costs. The research indicates that, when single trailer freight costs are two or more times greater than the inventory carrying costs, switching from single trailers to LCVs will in all likelihood greatly reduce the shipper's annual total logistics cost. On the other hand, when inventory carrying costs are roughly the same as or greater than the single trailer freight costs, the chances are good that switching from single trailers to LCVs will increase the shipper's annual total logistics cost.

No single variable or combination of variables among the ones considered in this study appears to be highly effective at predicting how much or to what degree an individual shipper's annual total logistics cost would change as a result of switching to some type of LCV. The influence of product value, in particular, is much smaller than is commonly expected. Product value is significant only when annual traffic lane volumes fall below 15,000 cwt (680,385 kg) or 350,000 ton-mi (510,650 metric ton-km). Only at low annual shipment volumes do higher product values significantly increase the chances that LCV use will increase the shipper's total logistics cost. Other factors such as annual lane volume and lane distance are good indicators of whether or not a shipper would benefit from using LCVs, but they are not highly significant estimators of the amount that would be saved or lost. Further research with more detailed shipper data will be needed to produce better logistics cost models for alternative truck sizes and weights.

Given the significant potential benefits of LCVs to truckload shippers as indicated by the analysis, the next question is to what extent would shippers nationwide switch from using single trailers to some type of LCV. Using data from the 1987 Truck Inventory and Use Survey (TIUS), an attempt was made to answer this question. The resulting estimates of nationwide intramodal diversion to LCVs vary depending on GVW limits, the difference between LCV and single trailer freight rates, and the minimum percent logistic cost savings necessary before shippers would switch to LCVs. For example, given weight limits of 115,000 lb (52,164 kg) for Rocky Mountain doubles and 131,000 lb (59,422 kg) for turnpike

doubles and LCV freight rates equal to current single trailer freight rates, the estimated nationwide intramodal diversion to LCVs range from 28 percent to 36 percent for weight-limited or high density freight and from 38 percent to 51 percent for cube-limited or low density freight. The magnitude of this diversion is estimated to be 1.1 billion to 1.5 billion truck-mi (1.8 billion to 2.4 billion truck-km) for high density freight and 1.5 billion to 2.1 billion truck-mi (2.4 billion to 3.4 billion truck-km) for low density freight out of an estimated base of 4.1 billion truck-mi (6.5 billion truck-km) in 1987. The base figure represents the number of miles operated by truck tractors pulling loaded single enclosed dry van semi-trailers with at least two axles on trips at least 200 mi (322 km) long. More research with better data and more robust logistics cost models is needed to determine whether this much diversion would actually occur and what the cumulative nationwide impact on shippers' total logistics cost would be.

Because of the small number of rail boxcar and intermodal observations in the shipper survey data, it was not possible to estimate the amount of diversion that might occur from rail to LCVs. The research indicates, however, that turnpike doubles operating under higher than existing GVW limits could reduce shippers' annual total logistics cost enough to induce some shippers to switch from rail boxcars and intermodal to LCVs. Additional research is needed to determine how much rail boxcar and truck-rail intermodal freight might be diverted.

1. INTRODUCTION

BACKGROUND

Allowable limits on truck size and weight has been a recurring issue at both the State and Federal level since the earliest days of motor carriers and public roadbuilding. Lately the issue has been raised once again. The Surface Transportation Assistance Act of 1982 increased the allowable width and length of tractor-trailer combinations and permitted the use of double trailer combinations on Interstates and designated Federal aid primary highways. The Surface Transportation and Uniform Relocation Assistance Act of 1987 provided for studies to be undertaken that would investigate the effects of even longer and heavier tractor-trailer configurations. The American Association of State Highway and Transportation Officials (AASHTO) also requested a study of new approaches to regulating truck size and weight. The resulting studies examined the effects of longer combination vehicles (LCVs) on motor carrier productivity, highway safety, highway capital and maintenance costs, and the transportation costs of shippers and receivers.^(1,2,3) Although some of these studies have considered the effects of LCVs on shippers' transportation costs, most have not explicitly looked at each component of a shipper's total logistics cost and how it might affect the demand for LCV service.

Recent preliminary research provided some initial insight into the relationship between a shipper's logistics costs and the economic advantages of LCVs.⁽⁴⁾ The study revealed that the net benefits of larger truck sizes and weights to shippers were sensitive to product value, length of haul, and lane volume. In particular, the study found that the user's inventory carrying costs comprised an increasingly larger proportion of the total logistics cost as product value increased and as shipping distance and lane volume decreased. The results indicated that certain combinations of product value, shipment distance, and annual lane volume can increase inventory carrying costs to the point where they offset the transportation cost savings offered by longer combination vehicles.

The results of the above study were based on data from a small sample of shippers and covered only a few types of products. A need existed to extend this firm-level research to a broader range of industries, product values and densities, shipment distances, and annual volumes. There also existed a need to develop, test, and implement models to scale the research findings from the level of the individual shipper or firm to the national level so as to provide nationwide estimates of the effects of Federal truck size and weight policy options. The research described in this report was undertaken to satisfy these needs.

RESEARCH OBJECTIVES

The main objectives of this research were the following:

- Analyze the effects of Federal truck size and weight policy options on shippers' component logistics costs.
- Estimate the nationwide diversion of freight from conventional, single trailer truck configurations and from other modes to LCVs, based on the results of the above analysis.

The study attempted to complement the knowledge gained from previous studies by looking explicitly at how different truck sizes and weights can affect the component logistics costs of individual shippers. The intent was to acquire a broader perspective on the productivity gains and economic implications of changes in Federal truck size and weight policy.

ORGANIZATION OF THE REPORT

The research findings were based on a mail and telephone survey of shippers and a mathematical model for computing a firm's logistics costs. Chapter 2 discusses what information was collected from shippers and how the sample was obtained. It also describes the Freight Transportation Analyzer (FTA), a computer program which implements the model for calculating logistics costs. Chapter 2 also contains statistics on the size and characteristics of the sample.

Chapter 3 presents the results of the FTA model for those companies in the survey sample who shipped their products in single semi-trailers of various sizes. It describes the overall effects of LCVs on the total logistics cost of these shippers as well as the influence of such factors as product value, shipment distance, annual lane volume, and combinations of these factors. It also provides estimates of LCV diversion rates under various situations.

Chapter 4 covers the results of the FTA model for companies in the survey sample that shipped via rail boxcar or trailer-on-flatcar (TOFC) intermodal service. Because of the much smaller sample sizes involved, the discussion is not as extensive as that of Chapter 3. Nevertheless, Chapter 4 discusses the overall effects of LCVs on the logistics costs of rail and intermodal shippers as well as the influence of rail and intermodal freight rates on intermodal diversion to LCVs.

In Chapter 5, the results of the firm-level analysis are applied to data from the 1987 Truck Inventory and Use Survey (TIUS) to estimate the nationwide diversion of truck traffic to LCVs. Chapter 5 describes the estimation methodology and compares the resulting estimates with those from a previous study.

Chapter 6 summarizes the major findings and limitations of the research.

Throughout this report the terms "rate", "freight rate", and "freight charge" are used interchangeably. They refer to a carrier's price for shipping a certain quantity of cargo

between an origin and a destination. In practice this price could be quoted per unit, per hundredweight (cwt), or per mile. In this report, unless noted otherwise, carrier rates or charges are specified in dollars per mile for a truckload or a boxcarload shipment. The terms "transportation cost" and "freight cost" refer to the total amount that a shipper pays for a shipment between an origin and a destination. It is equal to the carrier's rate per mile times the shipment distance or the carrier's rate per hundredweight times the weight of the shipment. A shipper's annual freight cost is equal to the annual number of shipments times the carrier's freight charge per shipment.

2. DATA COLLECTION AND LOGISTICS COST ANALYSIS METHODOLOGY

INTRODUCTION

The firm-level analysis was based on data from a mail and telephone survey of companies in selected industries. The information provided by the surveyed companies was then entered into a computer program called the Freight Transportation Analyzer (FTA) to calculate component logistics costs for alternative types of longer combination vehicles as well as for the shipper's current primary mode of transportation.

This chapter addresses the survey methodology and the FTA. It identifies the kinds of information requested from the surveyed companies, describes how the sample of shippers was obtained, and presents statistics on the size and characteristics of the resulting sample. The discussion then turns to the FTA, including a description of its input and output. The chapter concludes with a description of the size, structure, and characteristics of the resulting FTA datasets.

SHIPPER SURVEY

Information Collected

The survey was designed to collect product information, freight flow data, and logistics cost information from each company.

Shippers were first asked to select and describe two of their company's primary products or product groups. The following data were requested for each principal product:

- Standard Industrial Classification (SIC) code or a written description of the product.
- Unit weight of the product in pounds where a unit represented the wholesale or shipping package such as a case, sack, bale, or tote.
- Cost of the product per pound or unit.
- Whether the product would cube-out or weigh-out; that is, whether the product would use up the cubic capacity of a 48-ft (14.6-m) long, 102-in (2.6-m) wide semi-trailer before reaching the maximum weight limit or whether it would reach the weight limit before filling up the cargo space of such a trailer.

The surveyed companies were then asked to select a representative short-distance (less than 500 mi [805 km]), medium-distance (500 to 1,000 mi [805 to 1,609 km]), and long-distance (over 1,000 mi [1,609 km]) lane or origin-destination pair for each of the two principal products and to provide the following freight flow data for each combination of lane and product:

- Origin city.
- Destination city.
- Lane distance in miles.
- Annual volume in pounds or number of shipments.
- Primary mode or type of carrier.
- Freight rate.
- Typical size of trailer, container, or rail boxcar used.
- Average weight per shipment.

In selecting representative lanes and freight flows, shippers were asked to observe the following guidelines:

- Consider only outbound movements where the shipper controlled the volume and route, such as shipments between a plant and a distribution center.
- Include only direct movements, not movements involving stop-offs or special handling.
- Include only movements in trailers, intermodal containers, or rail boxcars.
- Exclude shipments involving specialized equipment such as bulk hoppers or tankers.
- Include only full-sized shipments, defined as having one or more of the following characteristics:
 - At least 14,000 pounds (6,350 kg).
 - At least 18 pallets or slipsheets.
 - At least 50 percent of the cubic capacity of a 40-ft (12.2-m) long trailer or container or a rail boxcar.

Finally, shippers were asked to specify their company's average cost of processing an order or shipment and their company's inventory carrying cost. The latter was reported as a percentage of inventory value. Order costs involve the cost of handling the paperwork or electronic data interchange for an order or a shipment. Inventory carrying costs typically cover the cost of capital, warehousing, taxes, insurance, depreciation, and obsolescence. These two cost categories, along with transportation costs, form the primary components of shippers' total logistics cost.

Data Collection Methodology

The nature of the data to be collected posed some challenging problems in devising an effective data collection method. First, cost information is closely guarded in most firms. Some companies go so far as to impose corporate policies against disseminating any sensitive cost information. Second, four types of cost information were required: product costs, inventory carrying costs, order costs, and freight transportation costs (as well as traffic volume data). Information on all four of these cost categories is not necessarily maintained or controlled by one individual or even one functional unit within an organization. To provide all of the requested information, a company contact would in many cases have to coordinate with other functional groups, greatly increasing the likelihood of either an incomplete response or no response at all.

While a broad mix of products, company sizes, and shipment volumes was desirable, including all possible products and shipping patterns in the sample would have greatly increased the time and cost of running the FTA program and analyzing the results. Therefore, an effort was made to target the survey at companies matching the following profile:

- Ship in truckload or carload quantities.
- Use dry transportation equipment such as dry vans, containers, or boxcars instead of flatbeds, tankers, reefers, or bulk hoppers.
- Make direct shipments with little or no special handling requirements.

Because of these and other obstacles, three separate data collection efforts were eventually required to obtain an adequate sample size. Each effort employed a different sampling frame.

Phase One

The initial effort involved a mail and telephone survey, using as the sampling frame the 1992 edition of *The Official Directory of Industrial & Commercial Traffic Executives*

(commonly referred to as the *Bluebook*). Companies were randomly selected. To increase efficiency and ensure broad geographic coverage, samples were drawn from five base business regions:

- East: eastern New York, northern New Jersey, and southern Connecticut.
- South: Georgia and southern South Carolina.
- Midwest: northeastern Illinois, southern Wisconsin, northwestern Michigan, and northern Indiana.
- Southwest: Texas.
- West: southern California.

The sample was further stratified by two-digit SIC code to ensure a broad mix of basic commodities.

The randomly chosen companies were contacted by telephone and questioned about their current shipment patterns and their willingness to participate in the research. Approximately 3,700 phone calls were made in the effort to screen potential participants. Eligible companies received a five-page questionnaire along with a cover letter and a postage-paid, self-addressed return envelope. Follow-up phone calls were made when necessary two to three weeks after the initial contact to answer questions and improve the response rate.

The results of the initial data collection effort were as follows:

- 731 randomly selected companies were contacted and screened for eligibility.
- 251 companies were sent a questionnaire.
- 11 companies completed the survey satisfactorily, resulting in a response rate of only 4.38 percent.

Several factors contributed to the extremely low response rate. A major factor was the complexity of the information being requested, especially the logistics cost information. Many companies were able to provide freight flow data but were either unwilling or unable to specify their order processing and inventory carrying costs. Many of the small firms lacked the sophisticated logistics management necessary to interpret and respond properly to the detailed questions about logistics. Use of a general business directory for the sampling frame was another factor. As much as 20 to 30 percent of the information in such directories may be outdated. In addition, rules for inclusion in general business directories can be very broad, whereas the rules for eligibility for the survey were quite restrictive.

Consequently, many of the randomly selected firms were ineligible for the survey because they generally shipped in less-than-truckload (LTL) quantities. A third factor was the Commodity Flow Survey (CFS) being conducted at the same time by the U.S. Bureau of the Census. Many of the contacted firms were heavily involved in providing shipment data for the CFS and, consequently, were unable to take the time required to respond to this survey.

Phase Two

Because the survey was conducted by the Center for Logistics Research at The Pennsylvania State University, a directory of alumni with degrees in business logistics was readily available. This sampling frame was therefore used in the second data collection effort. Concentrating on business logistics alumni offered the following potential advantages:

- Penn State's large business logistics network allowed access to a wide number and variety of firms.
- Contacting individuals with advanced logistics training should greatly improve comprehension of the survey questionnaire.
- Loyalty to one's alma mater should increase the willingness to respond.
- The information in the alumni directory was of higher quality than that in many standard lists and directories.

As in the first data collection effort, alumni at prospective firms were contacted by telephone and questioned about their company's current shipment patterns and willingness to participate in the research. Eligible companies then received the survey questionnaire along with an introductory letter. Follow-up phone calls were made two to three weeks after the initial contact to answer questions and solicit cooperation.

The results of the second data collection activity were as follows:

- 271 companies were contacted and screened for eligibility.
- 187 companies were sent a questionnaire.
- 52 companies completed the survey satisfactorily, resulting in a response rate of 27.8 percent.

Phase Three

The third data collection effort involved mailing the survey questionnaire to approximately 500 companies chosen from the 1993 edition of the *Council of Logistics Management Membership Roster*. In this case no effort was made to screen the companies for eligibility except to ensure that no companies contacted during either of the previous data collection efforts were included in the mailing. Follow-up calls, however, were made two to three weeks after the initial mailing.

Only nine of the 500 companies responded satisfactorily, a response rate of only 1.8 percent.

Sample Size and Characteristics

The final shipper survey sample included 72 companies, and the resulting dataset contained 297 traffic lane observations. Table 1 shows a breakdown of these observations by type of product. Shipments of food and kindred products (SIC 20) and shipments of chemicals and allied products (SIC 28) together accounted for nearly half (47.5 percent) of the total number of lane observations. Paper and allied products (SIC 26) along with stone, clay, and glass products (SIC 32) contributed another 18 percent of the observations. Product values ranged from \$0.0045 per lb (\$0.01 per kg) to \$75.00 per lb (\$165.35 per kg) with an average of \$4.14 per lb (\$9.13 per kg). Table 2 shows the distribution of transport modes and types of equipment among the observations. In over 80 percent of the cases, trucks were the principal mode used in the traffic lane. About one out of every six observations involved rail transport, either trailer-on-flatcar (TOFC) or boxcar.

Inventory carrying costs ranged from 2.0 percent of inventory value to 140 percent. The average inventory carrying cost was 18.1 percent of inventory value. Of the 72 companies responding to the survey, 13 were unable to provide any information on their inventory carrying costs. Some companies stated that their current product costs and interest rates were so low that inventory carrying costs were not considered in making daily transportation decisions.

Fixed order costs varied between \$2.20 and \$320.00 per shipment. The average was \$44.53. Only 53 of the 72 companies in the sample were able to specify their fixed order costs.

Table 1. Distribution of traffic lane observations in the shipper survey
by type of product.

SIC	Product Group	Frequency
01	Agricultural Products - Crops	1
20	Food & Kindred Products	72
21	Tobacco Products	2
22	Textile Mill Products	5
24	Lumber & Wood Products	4
25	Furniture & Fixtures	11
26	Paper & Allied Products	27
27	Printing & Publishing	9
28	Chemicals & Allied Products	69
30	Rubber & Miscellaneous Plastics Products	9
32	Stone, Clay, & Glass Products	26
34	Fabricated Metal Products	7
35	Industrial Machinery & Equipment	6
36	Electronic & Other Electrical Equipment	9
38	Instruments & Related Products	11
24 & 34	Wood Products & Fabricated Metal Products	6
28 & 29	Chemicals & Petroleum Products	6
26 & 28 & 30	Paper, Chemicals, and Rubber Products	6
34 & 35	Fabricated Metal Products & Industrial Machinery	1
35 & 38	Instruments & Related Products	6
73\FAK	Freight All Kinds: Caulking, Roofing, Paint	4
	Total	297

Table 2. Distribution of traffic lane observations in the shipper survey
by mode of transportation and type of equipment.

Mode and Equipment	Frequency	Percent
Truck:	242	81.5
40-ft trailers	3	1.0
45-ft trailers	26	8.8
48-ft trailers	169	56.9
53-ft trailers	11	3.7
45- & 48-ft trailers	8	2.7
48- & 53-ft trailers	18	6.1
40-, 45- & 48-ft trailers	3	1.0
Unspecified trailer size	4	1.3
Intermodal:	26	8.8
40-ft trailers/containers	3	1.0
45-ft trailers/containers	4	1.3
48-ft trailers/containers	12	4.0
45- & 48-ft trailers/containers	3	1.0
48- & 53-ft trailers/containers	2	0.7
40-, 45- & 48-ft trailers/containers	2	0.7
Truck & Intermodal:	3	1.0
48-ft trailers	2	0.7
40-, 45- & 48-ft trailers	1	0.3
Rail:	25	8.4
50-ft boxcars	17	5.7
60-ft boxcars	8	2.7
Barge:	1	0.3
Total	297	100.0

Metric conversion: 1 ft = 0.3048 m

FREIGHT TRANSPORTATION ANALYZER

The Freight Transportation Analyzer (FTA) is a personal computer-based program that calculates not only the freight costs of various transportation options but the total logistics cost as well, including the cost of carrying inventories at the origin and destination. It essentially implements a deterministic economic order quantity (EOQ) model adapted to incorporate transportation costs.

The FTA program takes as input data about the product, the transportation alternatives, related costs at the origin and destination, and the inventory management system at the destination. Product data include unit weight, annual demand for the product at the destination, and product value at the origin. Transportation alternatives are described in terms of maximum quantity per shipment, fixed charges per shipment, and average transit time. Cost data include fixed order costs per shipment and inventory carrying costs in transit and at the destination. Input data on the inventory management system at the destination include the administrative lead time, the inventory review period, and the frequency at which demand forecasts are updated. In addition to these data, the FTA also accepts input for many other variables including the accuracy of a firm's demand forecasts, transit time variability, in-transit damage factors, and production scheduling. These latter variables, however, were not considered important to the objectives of this study.

The output of the FTA program is a detailed breakdown of a shipper's total annual logistics cost associated with each transportation alternative for a given product and traffic lane. In this study the detailed costs were summarized into three components:

- Annual freight cost.
- Annual fixed order cost.
- Annual inventory carrying cost.

The FTA was run on each product-lane observation for which complete information was provided. Because some companies could not provide data on their inventory carrying cost or their fixed order cost, not all 297 observations could be used. For each complete product-lane observation, the FTA calculated the freight, order, and inventory carrying costs for the shipper's current mode of transport as well as for each of the following two types of longer combination vehicle:

- Rocky Mountain double, which is a tractor pulling a 48-ft (14.6-m) trailer followed by a 28-ft (8.5-m) trailer.
- Turnpike double, which is a tractor pulling two 48-ft (14.6-m) trailers.

For product-lane observations involving shipments that typically weigh-out, two FTA cases were generated, one for each of the two gross vehicle weight (GVW) scenarios defined in table 3. This table shows the GVW limit and typical payload for each type of LCV in each scenario. The difference between the GVW limit and typical payload is greater than the tare weight of the LCV because it is generally not possible to completely fill the cubic capacity of both trailers. Under the low weight capacity scenario, the current GVW limit of 80,000 lb (36,288 kg) is retained for both types of LCV. Because of the extra tare weight of a 48-ft (14.6-m) trailer over a 28-ft (8.5-m) trailer, the typical payload for a turnpike double under this scenario is less than the typical payload for a Rocky Mountain double. The GVW limits are higher under the high weight capacity scenario and are set to take advantage of the additional cubic capacity offered by each type of LCV. The higher GVW limits, however, are not in proportion to the additional cubic capacity. They are affected by the Federal Bridge Formula, which is designed to protect bridges, especially those with relatively long spans, from the additional weight. In both GVW limit scenarios, the base case was the shipper's current mode of transport under existing GVW limits.

Table 3. Weight capacity of longer combination vehicles under two gross vehicle weight (GVW) limit scenarios.

Scenario	LCV Type	GVW Limit (lb)	Payload (lb)
Low weight capacity	Rocky Mountain Double	80,000	59,500
	Turnpike Double	80,000	54,500
High weight capacity	Rocky Mountain Double	115,000	79,500
	Turnpike Double	131,000	93,000

Metric conversion: 1 lb = 0.4536 kg

For lane observations involving shipments that typically cube-out, the number of FTA runs made for each observation depended on the current payload weight. Only one FTA run was necessary if the current payload was less than 38,000 lb (17,237 kg). Because cubic capacity rather than GVW is the limiting factor for these shipments, the results of the FTA program would have been the same for each GVW scenario. Therefore, only one FTA run was necessary for each of these lane observations, and its output was used for both GVW scenarios. The cubic capacity ratios shown in table 4 were used to determine shipment size and, therefore, the number of shipments required to accommodate the annual lane volume under each alternative mode of truck transport. Most of the observations of shipments that typically cube-out had current payloads of less than 38,000 lb (17,237 kg). For the few observations of shipments that typically cube-out and weigh 38,000 lb (17,237 kg) or more, two FTA runs were made. One run used the GVW limits and typical payloads for the low weight capacity scenario. The other run was based on either the GVW limits and typical

payloads for the high weight capacity scenario or the cubic capacity ratios shown in table 4, depending on whether GVW or cubic capacity was the limiting factor.

Table 4. Cubic capacity of longer combination vehicles compared to single trailers of various sizes.

Trailer Size or Combination	Capacity (ft ³)	Rocky Mt Double Ratio	Turnpike Double Ratio
40-ft x 96-in	2,700	2.06 : 1	2.60 : 1
45-ft x 96-in	3,050	1.82 : 1	2.30 : 1
48-ft x 102-in	3,500	1.59 : 1	2.00 : 1
53-ft x 102-in	3,850	1.44 : 1	1.82 : 1
Rocky Mt Double	5,550	n/a	n/a
Turnpike Double	7,000	n/a	n/a

Metric conversion: 1 ft³ = 0.028 m³

The payload and cubic capacity guidelines shown in tables 3 and 4 were compiled from numerous sources, including the Western Highway Institute, the American Trucking Associations, interviews with shippers and carriers, and previous studies of longer combination vehicles.

A number of companies in the shipper survey reported a range of product values rather than a single value. For these product-lane observations, one or two FTA runs were made based on the high product value and another one or two runs were made using the low product value. The number of FTA cases generated for each product value depended on the weight of the payload and whether the shipment typically cubed-out or weighed-out, as described above.

If a company reported using more than one mode or trailer size in a lane, the one chosen for the FTA run was the mode or trailer size involved in transporting the bulk of the annual lane volume.

An important input to the FTA is the carrier's rate or freight charge for each alternative mode. Shippers provided this information in the survey for their current mode. For each of the LCV alternatives, two LCV rate assumptions were considered for shipments currently made by truck. The first assumption was that shippers would pay the same rate for each type of LCV that they were currently paying for single trailer transport. This

assumption is not unrealistic. In a recent survey of motor carriers who operate LCVs, 50 percent of the respondents stated that LCV operation had lowered their typical rates, and 46 percent said there was no significant difference.⁽⁵⁾ The FTA was therefore run on the basis of this first assumption. The second assumption was that LCV rates would be higher, reflecting the higher costs per mile of operating LCVs. This assumption was implemented by a derived set of factors which were applied to the annual freight costs calculated by the FTA under the first LCV rate assumption. Table 5 indicates these factors and how they were derived. The operating costs per loaded mile were taken directly from a previous study.⁽⁶⁾ These costs were based on the assumption that 15 percent of a vehicle's mileage is empty haul. The gross vehicle weights shown in the table were the ones used in the previous study. Although they differ slightly from the gross vehicle weights assumed for the high and low weight capacity scenarios, the costs that vary with weight do not change rapidly enough to alter the derived set of factors significantly.

Table 5. LCV rate adjustment factors based on a comparison of operating costs per loaded mile.

Vehicle Type	GVW Scenario	GVW (lb)	Cost per Loaded Mile	Percent Change	Rounded Rate Adjustment Factor
48-ft trailer	Base	78,000	\$1.25	0.0	1.00
Rocky Mt Double	Low Weight Capacity	80,000	\$1.37	+ 9.6	1.10
	High Weight Capacity	105,500	\$1.43	+ 14.4	1.15
Turnpike Double	Low Weight Capacity	80,000	\$1.49	+ 19.2	1.20
	High Weight Capacity	129,000	\$1.59	+ 27.2	1.30

Metric conversion: 1 ft = 0.3048 m; 1 mi = 1.609 km; 1 lb = 0.4536 kg

The second LCV rate assumption affected only the computation of the total annual freight cost for each FTA run. Calculation of annual order and inventory carrying costs by the FTA does not depend on the LCV rate. Consequently, there was no need to rerun the FTA for the second LCV rate assumption. Instead, the annual freight costs from the FTA runs were simply multiplied by the appropriate rate adjustment factors shown in table 5. The

revised annual freight costs were then added to the order and inventory carrying costs from the FTA runs to produce total logistics costs under the second LCV rate assumption.

The LCV rate assumptions described above applied only to product-lane observations where the current mode was truck. For lanes in which the product was currently shipped by rail boxcar or rail-truck intermodal, an LCV rate of \$1.30 per mi (\$0.81 per km) was used to run the FTA. Under the assumption that LCV operators will charge the same rate as currently charged for single trailers, this rate turned out to be perhaps a little too high. Nearly all of the rail and intermodal observations involved either medium lane or long lane distances. The average single trailer freight charges paid by shippers in the survey were \$1.24 per mi (\$0.77 per km) for medium lane shipments and \$1.14 per mi (\$0.71 per km) for long lane shipments. On the other hand, under the assumption that LCV operators will charge higher rates for LCV service because of the higher operating costs involved, the assumed LCV rate of \$1.30 per mi (\$0.81 per km) was perhaps too low for some situations. After applying the rate adjustment factors in table 5 to the current single trailer rates charged shippers in the survey, the results showed that the average rate for Rocky Mountain doubles for medium lane distances would be \$1.36 per mi (\$0.85 per km) under the low weight capacity scenario and \$1.42 per mi (\$0.88 per km) under the high weight capacity scenario. For long lane shipments the respective rates would be \$1.25 per mi (\$0.78 per km) and \$1.31 per mi (\$0.81 per km). The average rates for turnpike doubles were determined to be \$1.48 per mi (\$0.92 per km) and \$1.61 per mi (\$1.00 per km) for medium lane shipments under the low and high weight capacity scenarios, respectively, and \$1.36 per mi (\$0.85 per km) and \$1.48 per mi (\$0.92 per km) for long lane shipments under the two GVW scenarios. The originally assumed LCV rate of \$1.30 per mi (\$0.81 per km), therefore, appeared to be a reasonable compromise. Because of the small number of rail and intermodal shippers in the sample, no effort was made to rerun the FTA for different LCV rates for these cases.

Table 6. Breakdown of FTA observations by current principal mode.

Current Mode	Frequency	Percent
Tractor + single trailer	176	77.2
Truck-rail intermodal	27	11.8
Rail boxcar	24	10.5
Barge	1	0.5
Total	228	100.0

Altogether some 347 runs of the FTA were made. The output was organized into two datasets, one for each GVW scenario. Each dataset contained 228 cases or observations.

Table 6 shows the breakdown of these cases by current principal mode. Each observation consisted of the annual freight cost, order cost, inventory carrying cost, and total logistics cost for the current mode, Rocky Mountain double LCV, and turnpike double LCV as determined by the FTA.

3. EFFECTS OF LCV USAGE ON THE LOGISTICS COSTS OF TRUCK SHIPPERS

INTRODUCTION

This chapter presents the results of the FTA runs for shipments currently handled by tractor and single trailer. It begins by addressing the overall effect of LCV use on the total logistics cost of current motor carrier users, showing how the cost consequences of LCV use can vary by type of LCV, GVW limits, and LCV rates relative to single trailer rates. It then looks at several individual factors and combinations of factors that could influence how much of an effect LCV use would have on a truck shipper's total logistics cost. Based on these findings, the chapter then considers how many shippers might switch from single trailer truck hauls to some type of LCV.

OVERALL EFFECTS

The FTA results indicated that, in a large majority of cases, companies would reduce their total logistics cost by switching from single trailer truck transport to some type of LCV. The extent to which a company's total logistics cost for a given product in a given lane would change as a result of switching depended on the type of LCV, GVW limits, and LCV rates relative to single trailer rates. Table 7 summarizes the FTA results with respect to these three parameters.

Two of the more noteworthy findings in table 7 are the large average and median percent reductions in total logistics cost associated with LCV usage and the wide range in the percent change in costs that can result from switching to LCVs. For example, under the high weight capacity scenario with LCV rates the same as current single trailer truck rates, the FTA calculated that use of Rocky Mountain doubles would lead to cost savings of at least 33 percent in half of the product-lane observations. Under the same situation, use of turnpike doubles would lead to cost reductions of at least 42 percent in half of the cases. For the vast majority of product-lane observations, switching to some type of LCV would reduce total annual logistics cost. The average reduction in total logistics cost for Rocky Mountain doubles ranged from 17 percent to 27 percent, depending on GVW limits and LCV rates relative to single trailer truck rates. For turnpike doubles the range in average cost reduction was between 13 percent and 32 percent. In some cases cost savings as high as 45 to 52 percent were predicted by the FTA for Rocky Mountain doubles and 48 to 59 percent for turnpike doubles. At the other extreme, significant cost increases were also possible. The FTA results revealed cases where switching to Rocky Mountain doubles would increase the shipper's total annual logistics cost by as much as 42 percent and switching to turnpike doubles would increase it by as much as 73 percent.

Table 7. Overall effect of LCVs on the total logistics cost of single trailer truck shippers by type of LCV, GVW limits, and relative LCV rates.

GVW Scenario	Relative LCV Rate	Percent Cost Reduction				% of Cases Cost Increase
		Minimum	Maximum	Average	Median	
Rocky Mountain Doubles						
Low Weight	Same	- 40.59	49.90	22.46	24.76	7.95
	Higher	- 41.59	45.13	17.10	18.49	10.23
High Weight	Same	- 40.59	51.73	26.89	32.78	7.95
	Higher	- 42.08	44.77	19.66	25.05	10.80
Turnpike Doubles						
Low Weight	Same	- 71.08	59.45	23.47	21.56	10.80
	Higher	- 72.66	51.89	13.40	9.34	17.61
High Weight	Same	- 71.08	59.45	32.38	42.37	10.80
	Higher	- 73.45	48.11	20.59	29.54	14.77

Notes: Negative percentages imply an increase in total logistics cost.

Percentages in the rightmost column are based on a sample size of 176 cases.

Higher GVW limits tended to increase the economic benefits of LCVs. The average and the median percent cost reduction resulting from the use of LCVs was generally higher under the high weight capacity scenario than under the low weight capacity scenario. The importance of higher GVW limits was especially noticeable for turnpike doubles. In going from an 80,000-lb (36,288-kg) to a 131,000-lb (59,422-kg) GVW limit, the average percent cost reduction for turnpike doubles increased between 7 and 9 percentage points, depending on the relative LCV freight rate. The increase in the median percent cost reduction was even larger at around 20 percentage points. For Rocky Mountain doubles, on the other hand, the effect of going from an 80,000-lb (36,288-kg) GVW limit to a 115,000-lb (52,164-kg) limit was an increase in the average percent cost reduction of only about 2½ to 4 percentage points.

Higher LCV rates had a noticeable but not tremendously large dampening effect on the generally favorable economic consequences of LCV use. Compared to the situation in which the LCV rate in each case was the same as the shipper's current single trailer truck rate, higher LCV rates based on higher operating costs per mile tended to reduce the average

percent cost reduction by around 5 to 12 percentage points, depending on LCV type and GVW limits. Again the effect was stronger for turnpike doubles than for Rocky Mountain doubles. Higher LCV rates also increased the number of cases where a shipper would experience an increase in total annual logistics cost by switching to LCVs, but only to a fairly small extent.

The relative attractiveness of the alternative truck configurations greatly depended on GVW limits. Table 8 shows the distribution of lane observations by type of truck configuration resulting in the lowest total logistics cost. When GVW limits were kept at their current level of 80,000 lb (36,288 kg), Rocky Mountain doubles held a slight edge over turnpike doubles. At current GVW limits, turnpike doubles are virtually worthless for truckload shipments that typically weigh-out in single trailers. The FTA results indicated, however, that for low-density products that normally cube-out in single trailer truckload shipments, turnpike doubles could be advantageous even under current weight limits. Turnpike doubles were by far the most cost-effective configuration under the high weight capacity scenario where shipments that normally weigh-out in single trailers can take advantage of the additional cubic capacity offered by twin 48-ft (14.6-m) trailers.

Table 8. Truck configuration resulting in the lowest total logistics cost by GVW limits and relative LCV rates.

Relative LCV Rate	Truck Configuration	Percent of Cases	
		Low GVW	High GVW
Same	Single trailer	7.95	7.95
	Rocky Mountain double	48.30	9.66
	Turnpike double	43.75	82.39
Higher	Single trailer	10.23	10.80
	Rocky Mountain double	48.86	17.61
	Turnpike double	40.91	71.59

Higher LCV rates relative to current single trailer rates also influenced which configuration was the most economical in terms of total logistics cost. Compared to GVW limits, however, the effect was relatively modest. In general it was to increase the attractiveness of single trailers and Rocky Mountain doubles at the expense of turnpike doubles, particularly under the high weight capacity scenario.

INFLUENCE OF VARIOUS COST, PRODUCT, AND LANE VARIABLES

The FTA results presented in the previous section showed that use of LCVs would lower the total logistics cost of the surveyed shippers in the vast majority of cases. The results, however, also showed tremendous variation in the degree to which the total logistics cost would change. In an effort to explain this wide variation, a number of variables related to costs and to product and traffic lane characteristics were examined individually and in combination with each other to determine what effect they had on the percent change in total logistics cost.

Ratio of Freight to Inventory Costs

Switching from single trailer truck transport to an LCV entails trading off higher inventory carrying costs against lower shipping costs. The degree to which using LCVs raises or reduces a firm's total logistics cost could depend on the comparative magnitude of the firm's freight and inventory carrying costs using single trailers. If the inventory carrying cost of a commodity is much smaller than the cost of shipping it in single trailer truckload quantities in a given traffic lane, then switching to an LCV will probably not increase the inventory carrying cost more than it decreases the freight cost. The net result would be a reduction in total logistics cost. On the other hand, if the inventory carrying cost is already about the same as or greater than the cost of shipping, then switching from single trailers to LCVs would likely increase the inventory carrying cost more than it reduces the freight cost, resulting in an increase in the total logistics cost.

Figures 1 and 2 support the above hypotheses. Each figure is a plot of the percent reduction in total logistics cost as a result of switching to LCVs versus the ratio of freight cost to inventory carrying cost for single trailer transport. Figure 1 shows the relationship under the low weight capacity scenario while figure 2 corresponds to the high weight capacity scenario. Both figures are based on the assumption that LCV rates will be higher than single trailer rates; however, the patterns displayed in these plots were the same under the assumption that LCV rates would not differ from current single trailer truckload rates.

In the FTA results, the percent change in total logistics cost was highly sensitive to changes in the freight-to-inventory cost ratio for ratios below approximately 4.0. LCV usage always resulted in a lower total logistics cost when the freight cost for single trailer shipments was at least twice as large as the inventory carrying cost. The ratio at which LCVs went from reducing to increasing the total logistics cost was generally between 1.5 and 1.7. In most cases where the ratio was less than 1.0, meaning that the inventory carrying cost was already greater than the single trailer freight cost, use of LCVs resulted in a higher total logistics cost. The more the ratio dropped below 1.0 (that is, the more the inventory carrying cost increased over the freight cost), the greater the negative impact of LCV usage on the total logistics cost.

Figure 1. Percent reduction in total logistics cost using LCVs under low GVW limits as a function of freight to inventory cost ratio for single trailers.

Figure 2. Percent reduction in total logistics cost using LCVs under high GVW limits as a function of freight to inventory cost ratio for single trailers.

As figures 1 and 2 indicate, freight-to-inventory cost ratios in the FTA datasets were generally quite high. The median ratio was 10.28, and in 81.25 percent of the cases, the current single trailer freight cost was at least twice as large as the inventory carrying cost. There were only 12 cases (6.8 percent of the total) in which the inventory carrying cost exceeded the single trailer freight cost.

Figures 1 and 2 suggest an obvious way by which a firm could determine whether or not and to what extent it might benefit from using LCVs. The procedure is to determine the firm's inventory carrying cost and compare it to the cost of shipping via single trailer truckloads in the traffic lane. If the shipping cost is greater than the inventory carrying cost by a factor of two or more, then use of LCVs would most likely be justified from the standpoint of lowering the firm's total logistics cost. Of course, market-related factors as well as others besides logistics costs may influence whether or not a firm will consider using longer combination vehicles.

Product Value

Given that LCVs are likely to be inappropriate in situations where the inventory carrying cost is nearly the same as or larger than the transport cost, it would seem that anything which increases the cost of storing a particular product would tend to reduce the attractiveness of LCVs. Many factors determine a firm's cost of holding inventory. They include interest rates, insurance, property taxes, capital, warehousing, depreciation, and obsolescence. Many of these factors, in turn, are affected by product value. For example, high-valued products often require special handling and storage in climate controlled warehouses. Thus, product value can greatly influence inventory carrying cost, although the relationship may sometimes be subtle and indirect. Nevertheless, the FTA results were used to test the hypothesis that, as product value increases, the positive effect of LCVs on total logistics cost decreases.

The product-lane observations in the FTA datasets encompassed a wide range of product values, varying from a minimum of \$0.02 per lb (\$0.04 per kg) to a maximum of \$75.00 per lb (\$165.35 per kg). Roughly one-third of the observations had product values under \$1.00 per lb (\$2.20 per kg) while another third had product values at or above \$3.00 per lb (\$6.61 per kg). Thus, the sample contained an adequate mix of high- and low-valued commodities with which to test the above hypothesis.

Table 9 shows the observed relationship between product value and percent cost reduction associated with use of LCVs for different LCV types, GVW limits, and relative LCV rates. Except for turnpike doubles under the low weight capacity scenario, the signs of the correlation coefficients generally supported the hypothesis that higher product values are associated with less favorable results from using LCVs. However, the magnitudes of the coefficients were small, indicating that the relationship is a fairly weak one. Product value

by itself, therefore, did not help to explain much of the wide variation in the impact of LCV use on total logistics cost.

Table 9. Correlation between product value and the percent reduction in total logistics cost resulting from LCV usage.

LCV Type	GVW Scenario	Relative LCV Rates	Correlation
Rocky Mountain Double	Low	Same	- 0.0373
		Higher	- 0.0101
	High	Same	- 0.1175
		Higher	- 0.1068
Turnpike Double	Low	Same	0.0412
		Higher	0.0972
	High	Same	- 0.0886
		Higher	- 0.0714

Inventory carrying cost, expressed as a percentage of inventory value, varied between 2 percent and 140 percent in the FTA datasets. This variable was multiplied by product value to form a composite variable which was then correlated with the percent reduction in total logistics cost from using LCVs. The results are shown in table 10. The magnitudes of the correlation coefficients were once again very small, indicating very little correlation between the composite variable and the cost effects of LCV usage. Moreover, the signs of the coefficients in this case were inconsistent. They indicated a negative correlation for the high weight capacity scenario and a positive correlation for the low weight capacity scenario. As was the case for product value alone, the result of multiplying product value by the inventory carrying cost expressed as a percentage of inventory value was not very helpful in explaining the FTA results.

Annual Lane Volume

As the demand for a product rises in a given traffic lane and the volume shipped to meet the demand increases, freight costs tend to account for a larger proportion of the total logistics cost. Conversely, as lane volume decreases, inventory costs tend to increase as a percentage of total logistics cost.⁽⁴⁾ Heavy annual lane volumes, therefore, should favor the use of LCVs.

Table 10. Correlation between percent cost reduction from using LCVs and the composite variable formed by multiplying product value by the inventory carrying cost expressed as a percentage of inventory value.

LCV Type	GVW Scenario	Relative LCV Rates	Correlation
Rocky Mountain Double	Low	Same	0.0271
		Higher	0.0465
	High	Same	- 0.0487
		Higher	- 0.0448
Turnpike Double	Low	Same	0.0939
		Higher	0.1346
	High	Same	- 0.0225
		Higher	- 0.0130

Annual lane volumes for truck shipments in the FTA datasets varied considerably. The smallest volume was 351 cwt (15,921 kg), while the largest was 2,970,000 cwt (134,716,230 kg). Half of the observations involved annual lane volumes of 25,000 cwt (1,133,975 kg) or more.

The FTA results indicated that annual lane volume does influence the effect of LCVs on total logistics cost. Table 11 shows the percent reduction in total logistics cost from using LCVs at three levels of annual lane volume. Below annual volumes of 5,000 cwt (226,795 kg), the effectiveness of LCVs dropped sharply. In fact, the majority of cases in which LCV usage increased the total logistics cost involved annual lane volumes of less than 5,000 cwt (226,795 kg). The average effect of LCVs at the lowest volume level ranged from a 3.39 percent increase in total logistics cost for turnpike doubles operating under high GVW limits and higher rates relative to single trailer rates to a 9.62 percent decrease in total logistics cost for Rocky Mountain doubles operating under low GVW limits and rates equivalent to existing single trailer rates. At volumes above 5,000 cwt (226,795 kg), on the other hand, LCVs decreased total logistics cost by an average of 16 percent to 42 percent, depending on LCV type, GVW limits, and relative LCV rates. Under the low weight capacity scenario, the average impact of LCVs did not change much at volumes in the middle and upper ranges. Under the high weight capacity scenario, however, the average percent reduction in total logistics cost was about 7 percentage points higher for Rocky Mountain doubles and 9 to 10 percentage points higher for turnpike doubles at volumes over 25,000 cwt (1,133,975 kg) compared to volumes between 5,000 and 25,000 cwt (226,795 to 1,133,975 kg).

Table 11. Average percent reduction in total logistics cost from use of LCVs for different levels of annual lane volume.

LCV Type	GVW Scenario	Relative LCV Rates	Annual Lane Volume (cwt)		
			Under 5,000	5,000 to 25,000	Over 25,000
Rocky Mountain Double	Low	Same	9.62 %	24.01 %	26.35 %
		Higher	5.33 %	18.75 %	20.53 %
	High	Same	9.10 %	26.65 %	33.88 %
		Higher	2.91 %	19.32 %	26.31 %
Turnpike Double	Low	Same	8.66 %	26.07 %	27.43 %
		Higher	1.41 %	16.35 %	16.06 %
	High	Same	6.53 %	32.48 %	42.24 %
		Higher	- 3.39 %	20.58 %	29.79 %

Metric conversion: 1 cwt = 45.359 kg

While the FTA results showed a logical overall relationship between annual lane volume and the cost-effectiveness of LCVs, the relationship was not a simple linear one. Moreover, the ability of annual lane volume to predict the actual amount of change in total logistics cost resulting from the use of LCVs was extremely weak. Table 12 shows the correlation between annual lane volume and percent cost reduction. In general, the correlation coefficients were very low. These coefficients along with the results shown in table 11 suggest that annual lane volume is a good indicator of the direction in which total logistics cost will change as a result of using LCVs but is a poor indicator of how much of a change will occur.

The correlation coefficients in table 12 were much higher for the high weight capacity scenario than for the low weight capacity scenario. In addition, the coefficients for turnpike doubles operating under low GVW limits indicated a negative correlation between annual lane volume and percent cost reduction. These results further illustrate the relative inefficiencies of operating LCVs in general and turnpike doubles in particular under current GVW restrictions. Much of the additional cargo space cannot be utilized. As a result, as the volume in the traffic lane increases, more LCV shipments are required than would be necessary under higher GVW limits. Consequently, freight costs also rise, in some cases more rapidly than they would if single trailers were employed.

Table 12. Correlation between annual lane volume and the percent reduction in total logistics cost resulting from LCV usage.

LCV Type	GVW Scenario	Relative LCV Rates	Correlation
Rocky Mountain Double	Low	Same	0.0632
		Higher	0.0497
	High	Same	0.1869
		Higher	0.1978
Turnpike Double	Low	Same	- 0.0110
		Higher	- 0.0524
	High	Same	0.1700
		Higher	0.1793

Lane Distance

Generally, the farther a product is shipped, the lower the freight cost is per mile or per hundredweight. However, the total freight cost tends to contribute to a greater share of the total logistics cost as lane distance increases. Conversely, as shipping distances decrease, inventory carrying costs tend to account for a higher proportion of the total logistics cost.⁽⁴⁾ LCVs, therefore, should become more cost-effective as shipping distances increase.

Table 13 shows the average percent reduction in total logistics cost from LCV usage for short, medium, and long lanes in the FTA datasets. Substantial cost savings from LCV use were possible in each lane distance category. However, at distances above 1,000 mi (1,609 km), LCVs always lead to a reduction in the total logistics cost when operating under high GVW limits. Only turnpike doubles running under low GVW limits at freight rates higher than current single trailer rates in some cases caused the total logistics cost to go up at distances above 1,000 mi (1,609 km). In the short and medium distance lanes, however, there was virtually no correlation between shipping distance and percent change in total logistics cost. Use of LCVs for short and medium distances produced very large cost savings in some cases and very large cost increases in others.

Annual Lane Ton-Mileage

Annual lane ton-mileage is a composite measure of annual lane volume and lane distance. In the FTA datasets, values ranged from 5,000 (7,295 metric ton-km) to

67,288,000 (98,173,192 metric ton-km). The average was 4,207,000 (6,138,013 metric ton-km) and the median was 736,000 (1,073,824 metric ton-km). Based on the observed effects of annual lane volume and lane distance, higher values of annual lane ton-mileage should increase the likelihood of higher cost savings from the use of LCVs.

Table 13. Average percent reduction in total logistics cost from use of LCVs for different traffic lane distances.

LCV Type	GVW Scenario	Relative LCV Rates	Lane Distance (mi)		
			Under 500	500 to 1,000	Over 1,000
Rocky Mountain Double	Low	Same	19.32 %	21.92 %	28.64 %
		Higher	14.28 %	16.58 %	22.73 %
	High	Same	23.66 %	26.37 %	33.21 %
		Higher	16.97 %	19.14 %	25.05 %
Turnpike Double	Low	Same	18.62 %	22.78 %	32.78 %
		Higher	8.90 %	12.80 %	21.99 %
	High	Same	27.25 %	31.59 %	42.34 %
		Higher	16.24 %	19.85 %	29.15 %

Metric conversion: 1 mi = 1.609 km

The average percent reduction in total logistics cost resulting from the use of LCVs is shown in table 14 for three levels of annual lane ton-mileage. The average impact of LCVs increased markedly in going from one level to the next. The jump in the average cost reduction percentages was especially acute between the low and middle annual lane ton-mileage categories. Most instances of LCVs causing the total logistics cost to rise occurred in the under 250,000 annual ton-mi (364,750 metric ton-km) category. Above 1,000,000 annual ton-mi (1,459,000 metric ton-km), use of LCVs always resulted in a decrease in total logistics cost except for turnpike doubles operating under low GVW limits at LCV rates higher than current single trailer rates. In the FTA datasets, nearly 44 percent of the cases involved annual flows greater than 1,000,000 ton-mi (1,459,000 metric ton-km), and nearly three-fourths of the observations involved annual flows of 250,000 ton-mi (364,750 metric ton-km) or more.

Table 14. Average percent reduction in total logistics cost from use of LCVs for different levels of annual lane ton-mileage.

LCV Type	GVW Scenario	Relative LCV Rates	Annual Lane Ton-Mileage		
			Under 250K	250K to 1,000K	Over 1,000K
Rocky Mountain Double	Low	Same	11.30 %	23.93 %	28.11 %
		Higher	6.96 %	18.67 %	22.09 %
	High	Same	11.72 %	26.87 %	35.97 %
		Higher	5.63 %	19.55 %	28.11 %
Turnpike Double	Low	Same	10.63 %	25.88 %	29.48 %
		Higher	3.01 %	16.09 %	17.76 %
	High	Same	10.39 %	32.91 %	45.16 %
		Higher	0.55 %	21.00 %	32.27 %

Metric conversion: 1 ton-mi = 1.459 metric ton-km

The correlation between annual lane ton-mileage and the percent reduction in total logistics cost resulting from the use of LCVs is shown in table 15. Again the magnitudes of the coefficients were rather low, although they were somewhat better than the correlation coefficients found for product value. Unlike the case for annual lane volume, the correlation between annual lane ton-mileage and percent cost reduction was consistently positive. In addition, the coefficients were higher for the high weight capacity scenario than for the low weight capacity scenario, particularly for turnpike doubles. This again points out the lower efficiency of LCVs operating under low GVW limits. As was the case for annual lane volume and lane distance, annual lane ton-mileage appeared to be better at indicating the likelihood of cost savings from LCV usage than it was at predicting how much savings could be expected.

Product Value and Annual Lane Volume

Neither product value nor annual lane volume showed much correlation with the percent change in total logistics cost resulting from use of LCVs, although the latter variable was a good indicator of whether or not LCVs would be beneficial to a shipper. These two variables were stratified and cross-tabulated to analyze their combined effect. Three categories of product value were defined:

Table 15. Correlation between annual lane ton-mileage and the percent reduction in total logistics cost resulting from LCV usage.

LCV Type	GVW Scenario	Relative LCV Rates	Correlation
Rocky Mountain Double	Low	Same	0.1216
		Higher	0.1160
	High	Same	0.1461
		Higher	0.1444
Turnpike Double	Low	Same	0.0980
		Higher	0.0769
	High	Same	0.1654
		Higher	0.1678

- Low - less than \$1.00 per lb (\$2.20 per kg).
- Medium - between \$1.00 per lb (\$2.20 per kg) and \$2.99 per lb (\$6.59 per kg).
- High - \$3.00 per lb (\$6.61 per kg) or more.

Approximately one-third of the 176 observations in each FTA dataset fell in each of the above categories. Annual lane volume was also separated into three categories, defined as follows:

- Low - less than 15,000 cwt (680,385 kg).
- Medium - between 15,000 cwt (680,385 kg) and 49,999 cwt (2,267,905 kg).
- High - 50,000 cwt (2,267,950 kg) or more.

Again, approximately one-third of the FTA cases fell in each of these categories. The cross-tabulation of product value and annual lane volume therefore yielded nine combinations or cells of these two variables with each cell having roughly the same number of observations.

The results of the cross-tabulation analysis are summarized in tables 16 through 19. Tables 16 and 17 cover Rocky Mountain doubles under the low and high weight capacity scenarios, respectively. Tables 18 and 19 cover turnpike doubles.

Table 16. Combined effect of annual lane volume and product value on total logistics cost using Rocky Mountain doubles under existing GVW limits.

Relative LCV Rates	Annual Lane Volume	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	19	25.27 %	31.02 %	5.26 %
		Medium	18	15.91 %	23.60 %	16.67 %
		High	25	7.91 %	9.33 %	32.00 %
	Medium	Low	17	26.57 %	24.18 %	0.00 %
		Medium	23	28.72 %	30.56 %	0.00 %
		High	15	23.52 %	23.25 %	6.67 %
	High	Low	19	24.98 %	24.68 %	5.26 %
		Medium	19	28.68 %	26.73 %	0.00 %
		High	21	23.99 %	24.12 %	0.00 %
Higher	Low	Low	19	19.71 %	24.90 %	5.26 %
		Medium	18	11.17 %	17.87 %	27.78 %
		High	25	3.73 %	5.44 %	40.00 %
	Medium	Low	17	20.45 %	18.45 %	0.00 %
		Medium	23	23.16 %	24.89 %	0.00 %
		High	15	19.02 %	18.32 %	6.67 %
	High	Low	19	18.56 %	17.78 %	5.26 %
		Medium	19	22.58 %	21.46 %	0.00 %
		High	21	18.76 %	18.28 %	0.00 %

Table 17. Combined effect of annual lane volume and product value on total logistics cost using Rocky Mountain doubles under higher GVW limits.

Relative LCV Rates	Annual Lane Volume	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	19	27.81 %	34.07 %	5.26 %
		Medium	18	18.53 %	23.89 %	16.67 %
		High	25	8.10 %	9.33 %	32.00 %
	Medium	Low	17	33.11 %	34.20 %	0.00 %
		Medium	23	30.72 %	31.79 %	0.00 %
		High	15	23.16 %	23.25 %	6.67 %
	High	Low	19	37.69 %	40.01 %	5.26 %
		Medium	19	38.79 %	38.81 %	0.00 %
		High	21	28.51 %	32.46 %	0.00 %
Higher	Low	Low	19	20.37 %	25.11 %	5.26 %
		Medium	18	11.86 %	16.64 %	27.78 %
		High	25	2.05 %	3.50 %	44.00 %
	Medium	Low	17	24.96 %	25.68 %	0.00 %
		Medium	23	22.77 %	23.20 %	0.00 %
		High	15	16.61 %	15.86 %	6.67 %
	High	Low	19	30.00 %	33.29 %	5.26 %
		Medium	19	31.14 %	31.93 %	0.00 %
		High	21	21.39 %	24.99 %	0.00 %

Table 18. Combined effect of annual lane volume and product value on total logistics cost using turnpike doubles under existing GVW limits.

Relative LCV Rates	Annual Lane Volume	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	19	28.51 %	27.71 %	5.26 %
		Medium	18	13.98 %	21.30 %	27.78 %
		High	25	5.82 %	7.34 %	44.00 %
	Medium	Low	17	28.40 %	19.24 %	0.00 %
		Medium	23	33.47 %	38.02 %	0.00 %
		High	15	29.77 %	29.26 %	6.67 %
	High	Low	19	20.72 %	17.95 %	5.26 %
		Medium	19	29.26 %	21.34 %	0.00 %
		High	21	25.85 %	20.27 %	0.00 %
Higher	Low	Low	19	17.97 %	13.79 %	15.79 %
		Medium	18	5.60 %	9.05 %	33.33 %
		High	25	- 1.22 %	1.16 %	48.00 %
	Medium	Low	17	16.52 %	7.72 %	11.76 %
		Medium	23	23.35 %	29.65 %	4.35 %
		High	15	22.27 %	21.42 %	13.33 %
	High	Low	19	7.07 %	4.52 %	21.05 %
		Medium	19	17.22 %	8.00 %	0.00 %
		High	21	15.91 %	11.82 %	4.76 %

Table 19. Combined effect of annual lane volume and product value on total logistics cost using turnpike doubles under higher GVW limits.

Relative LCV Rates	Annual Lane Volume	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	19	34.09 %	43.10 %	5.26 %
		Medium	18	19.27 %	28.51 %	27.78 %
		High	25	4.75 %	7.34 %	44.00 %
	Medium	Low	17	42.99 %	44.75 %	0.00 %
		Medium	23	38.82 %	41.93 %	0.00 %
		High	15	28.90 %	29.26 %	6.67 %
	High	Low	19	45.72 %	49.33 %	5.26 %
		Medium	19	47.27 %	47.34 %	0.00 %
		High	21	36.31 %	41.57 %	0.00 %
Higher	Low	Low	19	21.94 %	30.19 %	10.53 %
		Medium	18	8.50 %	16.97 %	33.33 %
		High	25	- 4.93 %	- 1.92 %	60.00 %
	Medium	Low	17	29.78 %	31.45 %	0.00 %
		Medium	23	25.91 %	27.97 %	4.35 %
		High	15	18.36 %	17.50 %	6.67 %
	High	Low	19	32.85 %	35.95 %	5.26 %
		Medium	19	34.56 %	34.17 %	0.00 %
		High	21	24.67 %	29.59 %	0.00 %

The effect of product value was noticeable mainly for annual lane volumes under 15,000 cwt (680,385 kg). At these low volumes, the average and median percent reduction in total logistics cost from using LCVs dropped considerably as product value increased. In addition, the percentage of cases in which LCV use resulted in an increase in the total logistics cost rose significantly with each successively higher level of product value when the annual lane volume was low. On the other hand, even when the annual lane volume was low, the average percent cost reduction was above the overall average when the product value was low, as a comparison with table 7 showed. Consequently, the likelihood that LCVs would actually increase the total logistics cost appeared to be a consequence of the combined effect of low lane volumes coupled with medium or high product values.

For annual lane volumes in the medium and high range, the effect of product value was not nearly as detectable. At these volume levels, the average and median cost reduction percentages were generally quite high regardless of the level of product value. Under the high weight capacity scenario, however, the average percent cost reduction for medium and high annual lane volumes was always lowest for product values in the highest category. Thus, high product value did appear to reduce the cost-effectiveness of LCVs at medium and high annual lane volumes, but generally not to the point where LCVs became counter-productive.

Product Value and Annual Lane Ton-Mileage

The same categories of product value defined above were also cross-tabulated with annual lane ton-mileage. The following three levels of annual lane ton-mileage were used, based on a plot of this variable against percent cost reduction as well as the distribution of annual lane ton-mileage values in the FTA datasets:

- Low - 350,000 ton-mi (510,650 metric ton-km) or less.
- Medium - Over 350,000 ton-mi (510,650 metric ton-km) but less than or equal to 1,000,000 ton-mi (1,459,000 metric ton-km).
- High - Over 1,000,000 ton-mi (1,459,000 metric ton-km).

The results of this cross-tabulation, summarized in tables 20 through 23, were similar to those obtained in the analysis of product value and annual lane volume. When the annual lane ton-mileage was low, the cost-effectiveness of LCVs was reduced considerably as product value increased. The combination of low ton-mileage and either medium- or high-valued products accounted for the majority of cases in which LCV usage resulted in an increase rather than a decrease in the total logistics cost. When annual lane ton-mileage was low but product value was also low, the average percent cost reduction was at or above the overall average. Above 350,000 annual ton-mi (510,650 metric ton-km), the effect of product value was not evident except under the high weight capacity scenario. At medium

and high levels of annual lane ton-mileage, high product values had a noticeable dampening effect on the cost-effectiveness of LCVs operating under higher GVW limits. However, the effect was not strong enough to make LCVs counter-productive. In fact, the cost reduction percentages were still quite large and in some cases were still well above the overall average.

INTRAMODAL DIVERSION TO LCVs

The FTA identified the truck configuration which had the lowest total logistics cost for each product-lane observation. As the results presented in the previous sections have shown, in most cases the lowest cost configuration was some type of LCV. Whether shippers in these cases would actually switch to LCVs is a question which cannot be answered directly from the responses to the shipper survey or from the FTA output. The answer undoubtedly depends on many complex factors, and each shipper may weight each factor differently. Nevertheless, total logistics cost is presumably one of the more important considerations.

The simplest approach to estimating an intramodal LCV diversion rate would be to assume that a shipper will use whichever trailer configuration produces the lowest total logistics cost. Most shippers, however, would probably not switch to an LCV configuration unless the resultant cost savings exceeded some fixed percentage of the firm's current total logistics cost. What that percentage might be is difficult to determine. Therefore, the decision was made to estimate a range of diversion rates based on different cost savings thresholds.

Table 24 indicates the sensitivity of intramodal LCV diversion rates to several factors: GVW limits, minimum percent reduction in total logistics cost needed for diversion to occur, and LCV freight rates relative to current single trailer rates. The table shows the percentages of FTA cases in which diversion was assumed to occur as well as the corresponding percentages of annual lane ton-mileage involved.

The following are some general observations from table 24:

- LCV diversion rates under the high weight capacity scenario tended to be larger than those under the low weight capacity scenario, although for minimum required cost savings below 20 percent, the differences were fairly small.
- Not surprisingly, as the minimum percent cost savings required to induce diversion increased, the diversion rate dropped considerably, especially under the low GVW scenario.

Table 20. Combined effect of annual lane ton-mileage and product value on total logistics cost using Rocky Mountain doubles under existing GVW limits.

Relative LCV Rates	Annual Lane Ton-Mileage	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	17	23.63 %	25.83 %	5.88 %
		Medium	16	15.25 %	21.02 %	18.75 %
		Low	24	5.20 %	5.95 %	37.50 %
	Medium	Low	15	25.82 %	30.77 %	6.67 %
		Medium	16	25.48 %	27.25 %	0.00 %
		High	11	20.24 %	16.26 %	0.00 %
	High	Low	23	26.84 %	25.07 %	0.00 %
		Medium	28	30.01 %	29.99 %	0.00 %
		High	26	27.19 %	27.22 %	0.00 %
Higher	Low	Low	17	18.16 %	20.53 %	5.88 %
		Medium	16	10.85 %	16.30 %	31.25 %
		High	24	1.45 %	2.23 %	45.83 %
	Medium	Low	15	20.10 %	24.76 %	6.67 %
		Medium	16	20.03 %	21.64 %	0.00 %
		High	11	15.50 %	12.66 %	0.00 %
	High	Low	23	20.20 %	18.61 %	0.00 %
		Medium	28	23.89 %	23.61 %	0.00 %
		High	26	21.82 %	21.24 %	0.00 %

Table 21. Combined effect of annual lane ton-mileage and product value on total logistics cost using Rocky Mountain doubles under higher GVW limits.

Relative LCV Rates	Annual Lane Ton-Mileage	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	17	26.07 %	30.28 %	5.88 %
		Medium	16	15.00 %	20.38 %	18.75 %
		High	24	4.40 %	5.95 %	37.50 %
	Medium	Low	15	31.20 %	34.63 %	6.67 %
		Medium	16	29.07 %	30.19 %	0.00 %
		High	11	21.93 %	16.26 %	0.00 %
	High	Low	23	38.96 %	37.26 %	0.00 %
		Medium	28	38.28 %	37.67 %	0.00 %
		High	26	30.84 %	32.71 %	0.00 %
Higher	Low	Low	17	18.78 %	22.49 %	5.88 %
		Medium	16	8.34 %	12.21 %	31.25 %
		High	24	- 1.05 %	0.37 %	50.00 %
	Medium	Low	15	23.68 %	25.79 %	6.67 %
		Medium	16	21.57 %	21.88 %	0.00 %
		High	11	15.20 %	10.86 %	0.00 %
	High	Low	23	30.73 %	29.46 %	0.00 %
		Medium	28	30.36 %	30.35 %	0.00 %
		High	26	23.37 %	25.29 %	0.00 %

Table 22. Combined effect of annual lane ton-mileage and product value on total logistics cost using turnpike doubles under existing GVW limits.

Relative LCV Rates	Annual Lane Ton-Mileage	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	17	28.23 %	32.69 %	5.88 %
		Medium	16	13.87 %	22.03 %	31.25 %
		High	24	2.42 %	0.84 %	50.00 %
	Medium	Low	15	26.40 %	25.27 %	6.67 %
		Medium	16	27.67 %	24.89 %	0.00 %
		High	11	23.80 %	18.21 %	0.00 %
	High	Low	23	23.58 %	18.83 %	0.00 %
		Medium	28	32.59 %	24.60 %	0.00 %
		High	26	31.35 %	30.92 %	0.00 %
Higher	Low	Low	17	18.11 %	24.28 %	17.65 %
		Medium	16	6.36 %	14.94 %	37.50 %
		High	24	- 3.88 %	- 5.21 %	54.17 %
	Medium	Low	15	15.04 %	11.92 %	13.33 %
		Medium	16	17.38 %	11.56 %	6.25 %
		High	11	15.55 %	10.80 %	9.09 %
	High	Low	23	9.69 %	4.74 %	17.39 %
		Medium	28	20.89 %	12.53 %	0.00 %
		High	26	21.53 %	22.87 %	3.85 %

Table 23. Combined effect of annual lane ton-mileage and product value on total logistics cost using turnpike doubles under higher GVW limits.

Relative LCV Rates	Annual Lane Ton-Mileage	Product Value	No. of Cases	% Cost Reduction		% of Cases Cost Increase
				Average	Median	
Same	Low	Low	17	32.15 %	44.61 %	5.88 %
		Medium	16	15.30 %	25.29 %	31.25 %
		High	24	- 0.57 %	0.64 %	50.00 %
	Medium	Low	15	38.84 %	43.10 %	6.67 %
		Medium	16	35.51 %	37.55 %	0.00 %
		High	11	26.70 %	18.21 %	0.00 %
	High	Low	23	48.61 %	48.88 %	0.00 %
		Medium	28	47.31 %	47.36 %	0.00 %
		High	26	39.80 %	42.25 %	0.00 %
Higher	Low	Low	17	20.22 %	28.94 %	11.76 %
		Medium	16	4.51 %	11.74 %	37.50 %
		High	24	- 9.28 %	- 8.18 %	66.67 %
	Medium	Low	15	26.57 %	30.19 %	6.67 %
		Medium	16	23.38 %	25.45 %	6.25 %
		High	11	15.72 %	9.21 %	0.00 %
	High	Low	23	35.01 %	35.01 %	0.00 %
		Medium	28	34.26 %	34.11 %	0.00 %
		High	26	27.70 %	29.78 %	0.00 %

Table 24. Percent of FTA cases and ton-mileage assumed to divert to LCVs under different GVW limits, cost savings thresholds, and relative LCV freight rates.

GVW Scenario	Min. % Savings	Relative LCV Rates	% of Cases Diverting to LCVs	% of Ton-Mileage Diverting to LCVs
Low Weight Capacity	> 0	Same	92.05 %	99.72 %
		Higher	89.77 %	99.67 %
	5	Same	89.20 %	99.66 %
		Higher	86.36 %	99.47 %
	10	Same	85.80 %	99.46 %
		Higher	80.11 %	96.81 %
	15	Same	80.11 %	96.81 %
		Higher	70.45 %	82.52 %
	20	Same	72.16 %	83.07 %
		Higher	48.86 %	59.12 %
	25	Same	53.98 %	70.15 %
		Higher	35.80 %	36.41 %
High Weight Capacity	> 0	Same	92.05 %	99.72 %
		Higher	89.20 %	99.66 %
	5	Same	89.20 %	99.66 %
		Higher	85.80 %	99.51 %
	10	Same	86.36 %	99.54 %
		Higher	78.98 %	93.85 %
	15	Same	81.25 %	96.87 %
		Higher	75.00 %	93.47 %
	20	Same	77.84 %	93.71 %
		Higher	69.32 %	83.51 %
	25	Same	75.00 %	93.44 %
		Higher	64.20 %	81.24 %

- LCV diversion rates were generally lower when LCV freight charges were higher than current single trailer freight charges. The differences between the diversion rates for the two LCV rate levels were relatively small when the minimum required cost savings was less than 10 percent. For cost savings of 10 percent and higher, however, the differences became increasingly larger.
- Regardless of the GVW scenario or the level of LCV freight charges, the estimated LCV diversion rates in table 24 were considerably high. Even with a minimum required cost savings of 15 percent, the estimated diversion rates were between 70 percent and 81 percent of the cases in the FTA datasets. This corresponded to 82.5 percent to 96.9 percent of the total annual ton-mileage for all of the survey observations.

4. EFFECTS OF LCV USAGE ON THE LOGISTICS COSTS OF RAIL AND INTERMODAL SHIPPERS

INTRODUCTION

This chapter presents the FTA results for those product-lane observations in which the current primary mode of transportation was either rail boxcar or truck-rail intermodal. The FTA datasets contained only 24 rail and 27 intermodal observations. Although these samples were too small for any multivariate analysis, some simple tabulations of the FTA results were made in order to gain some insight into the possible impact of LCVs on the total logistics cost of rail and intermodal shippers.

RAIL BOXCAR SHIPPERS

Table 25 summarizes the overall effect of LCV usage on the total logistics cost of the rail boxcar shippers. If LCVs were required to operate under 80,000-lb (36,288-kg) GVW limits, two-thirds of the rail shippers in the sample would incur a higher total logistics cost in the traffic lane as a result of switching to Rocky Mountain doubles. The average cost increase would be 36 percent, and in half of the cases, the cost increase would be 14 percent or more. The consequences of switching to turnpike doubles under existing GVW limits would be even more severe. The cost increase would be at least 26 percent in half the cases and would average nearly 49 percent. On the other hand, the FTA predicted a much different outcome for the high weight capacity scenario. If Rocky Mountain doubles were allowed to operate at gross vehicle weights up to 115,000 lb (52,164 kg), most of the rail boxcar shippers would experience a decrease in total logistics cost as a result of switching to the LCV mode. Although the average effect would be a 3.5 percent increase in the total logistics cost, in half of the cases, the total logistics cost would decrease by at least 13.7 percent. For turnpike doubles operating at gross vehicle weights up to 131,000 lb (59,422 kg), the FTA results were even more favorable for LCVs. In roughly 7 out of every 10 cases, switching from rail boxcars to turnpike doubles resulted in a lower total logistics cost. The average cost reduction was around 10.5 percent, and in half of the cases, the reduction was 25 percent or more.

Table 26 indicates that rail boxcars would continue to be the most cost-effective means of transport for current rail users under the low GVW scenario, while turnpike doubles would be the cost-effective mode in most cases under the high weight capacity scenario.

Under both GVW scenarios, the variation in the FTA results was extremely large. As table 25 shows, for some rail shippers, switching to LCVs could result in cost increases of well over 200 percent under the low GVW limit scenario and over 100 percent in the high

GVW limit situation. At the other extreme, switching to LCVs could reduce some rail shippers' total logistics cost by well over 50 percent.

Table 25. Overall effect of LCVs on the total logistics cost of rail boxcar shippers.

LCV Type	GVW Scenario	Percent Cost Reduction				% of Cases Cost Increase
		Minimum	Maximum	Average	Median	
Rocky Mt. double	Low	- 225.03	57.70	- 35.92	-13.82	66.67
	High	- 143.34	68.08	- 3.55	13.69	37.50
Turnpike double	Low	- 255.08	53.91	- 48.71	- 26.30	70.83
	High	- 108.01	72.54	10.58	24.92	29.17

Notes: Negative percentages imply an increase in total logistics cost.
Percentages in the rightmost column are based on a sample size of 24 cases.
The FTA used an LCV freight rate of \$1.30 per mi (\$0.81 per km).

Table 26. Transportation mode with the lowest total logistics cost for rail boxcar shippers.

Transportation Mode	Percent of Cases	
	Low GVW Scenario	High GVW Scenario
Rail boxcar	66.67	29.17
Rocky Mountain double	33.33	0.00
Turnpike double	0.00	70.83

Note: Percentages are based on a sample size of 24 cases.

To understand better why the overall effects of LCVs on rail boxcar shippers was so wide ranging, the shippers' current rail freight charge per mile was plotted against the percent reduction in total logistics cost. Figures 3 and 4 display the results for Rocky Mountain doubles under the low and high weight capacity scenarios, respectively. The corresponding charts for turnpike doubles are shown in figures 5 and 6.

Figure 3. Rail freight rate versus percent cost reduction using Rocky Mountain doubles under existing GVW limits.

Figure 4. Rail freight rate versus percent cost reduction using Rocky Mountain doubles under higher GVW limits.

Figure 5. Rail freight rate versus percent cost reduction using turnpike doubles under existing GVW limits.

Figure 6. Rail freight rate versus percent cost reduction using turnpike doubles under higher GVW limits.

Each figure shows a distinct relationship between the rail freight charge and the percent change in total logistics cost resulting from a switch to LCVs. The correlation between the two variables, shown in table 27, was fairly strong. The relationship, however, was clearly nonlinear. In fact, below a rail charge of roughly \$2.50 per mi (\$1.55 per km), each additional small decrease in the rail rate tended to result in an increasingly larger percent increase in total logistics cost from switching to an LCV. In other words, below a rail rate of around \$2.50 per mi (\$1.55 per km), the relative effect on total logistics cost of switching from rail boxcars to LCVs was much more sensitive to changes in the rail freight rate, implying much higher cross-elasticities in that range. This suggests that if a rail carrier's current freight charge was at or below this threshold rate, the carrier might have to reduce its rate by only a very small amount in order to offset any logistics cost benefits of LCVs and to prevent its traffic from diverting.

Table 27. Correlation between rail freight charge per mile and percent reduction in total logistics cost from switching to LCVs.

LCV Type	GVW Scenario	Correlation
Rocky Mountain Double	Low Weight Capacity	0.7042
	High Weight Capacity	0.7125
Turnpike Double	Low Weight Capacity	0.7016
	High Weight Capacity	0.7164

The rail freight rate at which there would be no difference in the total logistics costs of rail boxcars and LCVs varied by type of LCV and GVW limits. For Rocky Mountain doubles, this rate was between \$2.50 and \$3.50 per mi (\$1.55 to \$2.18 per km) under the low weight capacity scenario and between \$2.00 and \$2.50 per mi (\$1.24 to \$1.55 per km) under the high weight capacity scenario. For turnpike doubles, the breakeven rail rate was between \$2.50 and \$4.50 per mi (\$1.55 to \$2.80 per km) under existing GVW limits and around \$2.00 per mi (\$1.24 per km) under higher allowable GVW limits.

INTERMODAL SHIPPERS

The overall effects of switching from TOFC/COFC intermodal transportation to LCVs on the total logistics cost of intermodal shippers are summarized in table 28. As was the case for rail boxcar shipments, LCVs were generally less cost-effective compared to intermodal service when operating under restrictive GVW limits than when operating under much higher limits. In a slight majority of cases, use of Rocky Mountain doubles under the

low weight capacity scenario entailed an increase in the total logistics cost. The average cost increase was 4.2 percent. For turnpike doubles operating under existing GVW limits, nearly half of the cases showed an increase in the total logistics cost and half showed a decrease. On the average, however, the effect of switching to turnpike doubles was about a 5 percent increase in the total logistics cost. Under the high weight capacity scenario with its more liberal GVW restrictions, both types of LCV had much more favorable impacts. Use of Rocky Mountain doubles reduced the total logistics cost in two-thirds of the cases. The average cost reduction was 6.6 percent and in half of the cases the reduction was at least 11.4 percent. Use of turnpike doubles at higher GVW limits reduced the total logistics cost in 8 out of every 9 cases. The average cost reduction was over 16 percent and in half of the cases the reduction was over 26 percent. Table 29 indicates that none of the three modes was predominant under the low weight capacity scenario, while turnpike doubles were the most cost-effective mode in nearly 9 out of 10 cases under the high weight capacity scenario.

The variation in the effect of LCVs on the total logistics cost of intermodal shippers was not nearly as wide ranging as was the case for rail boxcar users. In fact, the range in the cost reduction percentages was about the same as that for single trailer truckload shippers. In an attempt to explain the variation, intermodal freight rates were plotted against percent reduction in total logistics cost. The results are displayed in figures 7 through 10 for each combination of LCV type and GVW scenario.

Table 28. Overall effect of LCVs on the total logistics cost of intermodal shippers.

LCV Type	GVW Scenario	Percent Cost Reduction				% of Cases Cost Increase
		Minimum	Maximum	Average	Median	
Rocky Mt. double	Low	- 60.35	26.93	- 4.20	- 1.36	55.56
	High	- 39.08	43.19	6.61	11.44	33.33
Turnpike double	Low	- 74.98	36.99	- 5.19	0.06	48.15
	High	- 62.83	50.87	16.84	26.18	11.11

Notes: Negative percentages imply an increase in total logistics cost.

Percentages in the rightmost column are based on a sample size of 27 cases.

The FTA used an LCV freight rate of \$1.30 per mi (\$0.81 per km).

Table 29. Transportation mode with the lowest total logistics cost for intermodal shippers.

Transportation Mode	Percent of Cases	
	Low GVW Scenario	High GVW Scenario
Intermodal	40.74	11.11
Rocky Mountain double	25.93	0.00
Turnpike double	33.33	88.89

Note: Percentages are based on a sample size of 27 cases.

The relationship between intermodal freight rate and LCV percent cost reduction was not nearly as well defined. Table 30 shows the correlation between the two variables. Except for Rocky Mountain doubles under the low weight capacity scenario, the correlation coefficients were not as large as those shown in table 27 between rail freight rate and LCV percent cost reduction. Nevertheless, some relationship was discernible. Under the low weight capacity scenario, switching to LCVs tended to increase the total logistics cost when the intermodal freight rate was below average and to decrease the total logistics cost when the intermodal freight rate was above average. With higher GVW limits, the FTA results showed that most intermodal shippers would have a lower total logistics cost using LCVs. Those few shippers who would have a higher total logistics cost were currently paying below average intermodal freight rates. Given the fairly narrow range of intermodal freight rates in the FTA datasets, the effect of Rocky Mountain doubles was quite sensitive to changes in intermodal freight rate under both GVW scenarios. The effect of turnpike doubles was likewise highly sensitive to changes in the intermodal freight rate, but only under the low weight capacity scenario.

Table 30. Correlation between intermodal freight charge per mile and percent reduction in total logistics cost using LCVs.

LCV Type	GVW Scenario	Correlation
Rocky Mountain Double	Low Weight Capacity	0.7244
	High Weight Capacity	0.6296
Turnpike Double	Low Weight Capacity	0.6012
	High Weight Capacity	0.5466

Figure 7. Intermodal freight rate versus percent cost reduction using Rocky Mountain doubles under existing GVW limits.

Figure 8. Intermodal freight rate versus percent cost reduction using Rocky Mountain doubles under higher GVW limits.

Figure 9. Intermodal freight rate versus percent cost reduction using turnpike doubles under existing GVW limits.

Figure 10. Intermodal freight rate versus percent cost reduction using turnpike doubles under higher GVW limits.

5. ESTIMATION OF NATIONWIDE LCV USAGE

INTRODUCTION

The second major objective of this study was to apply the results of the FTA program to the difficult problem of estimating the nationwide use of LCVs. The original intent was to predict both intramodal as well as intermodal diversion. However, the number of rail boxcar and truck-rail intermodal traffic lane observations in the shipper survey dataset was too small to develop a credible model of rail-to-LCV or intermodal-to-LCV diversion. Consequently, the effort was restricted to estimating the extent of diversion from single trailer truckload shipments to LCVs.

This chapter begins by presenting a simple intramodal diversion model based on the results of the FTA. It then describes how this model was applied to data from the 1987 Truck Inventory and Use Survey (TIUS) to estimate the nationwide diversion of single trailer truckload shipments to LCVs. The resulting projections are then presented and compared with projections from previous research.

INTRAMODAL DIVERSION MODEL

The FTA results indicated that annual lane ton-mileage was an important factor in determining whether or not a truckload shipper would benefit from LCVs. Product value was also a factor, but its effect was mainly visible at only very low annual lane volumes. Therefore, a simple classification model based on annual lane ton-mileage was developed using the shipper survey data and FTA results.

The model incorporated the following four factors:

- Annual lane ton-mileage.
- Gross vehicle weight limits.
- Minimum percent cost savings required before truckload shippers will be induced to switch from single trailers to LCVs.
- LCV freight rates relative to current rates for single trailer truckload shipments.

After careful study of plots of annual lane ton-mileage versus LCV percent cost reduction, the following four levels of annual lane ton-mileage were chosen for the model:

- Less than 50,000 (72,950 metric ton-km).

- 50,000 or more but less than 250,000 (364,750 metric ton-km).
- 250,000 or more but less than 1,000,000 (1,459,000).
- 1,000,000 or more.

The gross vehicle weight limit factor was represented by the high and low weight capacity scenarios. Because the minimum cost savings necessary to induce diversion to LCVs could not be deduced from the shipper survey and probably varies among shippers anyway, the model included levels of 0, 5, 10, 15, 20, and 25 percent. Finally, the relative LCV freight rate factor was represented by the following two levels:

- Same - shippers will pay the same rate for LCV service that they currently pay for single trailer truckload transport.
- Higher - shippers will pay a somewhat higher rate for LCV service, reflecting the generally higher operating cost per mile of LCVs.

The model was essentially a four-dimensional matrix whose cells were formed by the various combinations of the above four factors. The contents of each cell specified the percentage of annual ton-mileage estimated to divert to LCVs under the particular combination of factors defining the cell. These percentages were taken from the results of the FTA as it was applied to traffic lane data from the shipper survey.

The model is presented in table 31. The percent of ton-miles diverting increases as the level of annual ton-mileage increases. The model assumes that no diversion will take place for annual flows below 50,000 ton-mi (72,950 metric ton-km) in a traffic lane. Flows in that range were judged to be too small to justify use of LCVs even though the FTA results indicated that, in a few such cases, LCVs would reduce the total logistics cost. A company which ships 48,000-lb (21,773-kg) payloads in a 200-mi (322-km) traffic lane 10 times a year has an annual freight flow of 48,000 ton-mi (70,050 metric ton-km) in the lane. That is a rate of less than one truckload shipment per month. The assumption was made that a company would not consolidate such a small number of annual shipments by switching to LCVs.

ESTIMATION PROCEDURE

Correct application of the intramodal diversion model requires nationwide statistics on individual shipper or company traffic flows or a representative sample of company shipments. Unfortunately, such data were not available when this study was conducted. As a convenient but less than ideal substitute, individual truck data from the 1987 Truck Inventory and Use Survey (TIUS) were used.

Table 31. Percent of annual traffic lane ton-mileage that would divert to LCVs.

Annual Lane Ton-Mileage	Minimum % Cost Reduction Threshold					
	> 0	5	10	15	20	25
I. Low Weight Capacity - LCV rates same as single trailer rates						
< 50,000	0 %	0 %	0 %	0 %	0 %	0 %
50,000-249,999	80 %	71 %	67 %	59 %	55 %	34 %
250,000-999,999	96 %	96 %	91 %	82 %	64 %	52 %
1,000,000+	100 %	100 %	100 %	98 %	84 %	71 %
II. Low Weight Capacity - LCV rates higher than single trailer rates						
< 50,000	0 %	0 %	0 %	0 %	0 %	0 %
50,000-249,999	73 %	69 %	59 %	51 %	33 %	26 %
250,000-999,999	96 %	91 %	82 %	62 %	46 %	36 %
1,000,000+	100 %	100 %	98 %	84 %	60 %	36 %
III. High Weight Capacity - LCV rates same as single trailer rates						
< 50,000	0 %	0 %	0 %	0 %	0 %	0 %
50,000-249,999	80 %	71 %	65 %	59 %	59 %	51 %
250,000-999,999	96 %	96 %	93 %	83 %	73 %	67 %
1,000,000+	100 %	100 %	100 %	98 %	95 %	95 %
IV. High Weight Capacity - LCV rates higher than single trailer rates						
< 50,000	0 %	0 %	0 %	0 %	0 %	0 %
50,000-249,999	71 %	61 %	59 %	54 %	46 %	43 %
250,000-999,999	96 %	93 %	76 %	67 %	59 %	52 %
1,000,000+	100 %	100 %	95 %	95 %	85 %	83 %

Metric conversion: 1 ton-mi = 1.459 metric ton-km

The TIUS is conducted every five years by the U.S. Bureau of the Census. It is based on a stratified random sample of private and commercial trucks registered or licensed in each State during the survey year. The sample is divided into the following five strata:

- Stratum 1 - pickup.
- Stratum 2 - panel truck, van, utility vehicle, jeep, and station wagon on truck chassis.
- Stratum 3 - small single-unit truck with gross vehicle weight rating (GVWR) less than 26,000 lb (11,794 kg).
- Stratum 4 - large single-unit truck with GVWR greater than or equal to 26,000 lb (11,794 kg).
- Stratum 5 - truck tractor.⁽⁷⁾

Only stratum 5 was needed to estimate nationwide LCV usage. This stratum contained 34,619 individual truck records.

TIUS sample data are normally used to generate national estimates of the number of trucks and truck miles for various truck characteristics such as truck type and axle arrangement, major use, range of operation, operating weight, overall length, type of operation and jurisdiction, kind of carrier, and products carried. By making some assumptions, it is also possible to derive estimates of ton-mileage from TIUS sample data.

The TIUS provides a wide variety of data on truck activity, but it does have a few limitations, particularly with regard to the use to which it was put in this study. A major drawback is the fact that TIUS records represent individual truck activity rather than individual shipper activity. Another limitation is the absence of data on individual shipments. Thus, it is not possible to determine origin-destination or traffic lane flows directly from the TIUS data. A third weakness is the fact that reported annual mileage in many cases is based on the truck owner's own rough estimates rather than on actual odometer readings.⁽⁸⁾

Despite these problems, the TIUS dataset does contain several data items that appeared to be especially useful for estimating nationwide LCV usage. Table 32 lists the pertinent fields or data items that were selected from the TIUS records on the public use tape.

The remainder of this section describes the procedure that was followed to derive estimates of intramodal diversion to LCVs nationwide.

Table 32. Definitions of relevant data items selected from 1987 TIUS public use records.

Field Name	Definition
EXPFAC	Expansion or weighting factor
BODTYP	Body type of vehicle or trailer
EMPWGT	Empty weight of the vehicle (lb)
AVGWGT	Average weight when carrying a typical payload (lb)
MAXWGT	Maximum gross weight at which vehicle was operated (lb)
PCARSZ	% of annual mileage vehicle carried payloads filling its max. cargo size
PCARWT	% of annual mileage vehicle carried payloads at max. cargo weight
VEHTYP	Vehicle type
ANNMIL	Miles vehicle was driven during 1987
PLONG	% of annual mileage for trips beyond 200-mi radius of home base
PRFOOD	% of annual mileage hauling processed foods & tobacco products
BLDGMA	% of annual mileage hauling gravel, sand, concrete, flat glass, etc.
LUMBER	% of annual mileage hauling lumber & fabricated wood products
PAPER	% of annual mileage hauling paper & paper products
CHEM	% of annual mileage hauling chemicals and/or drugs
PETROL	% of annual mileage hauling petroleum & petroleum products
PLASTK	% of annual mileage hauling plastics and/or rubber products
FABMTL	% of annual mileage hauling fabricated metal products
MACHINE	% of annual mileage hauling machinery
FURN	% of annual mileage hauling furniture and/or hardware
GLASS	% of annual mileage hauling glass products
TEXTIL	% of annual mileage hauling textiles & apparels
MSCMFG	% of annual mileage hauling misc. products of manufacturing
AXLRE	Code indicating total number of axles on truck/trailer combination

In the first step, TIUS stratum 5 records meeting the following criteria were selected:

- Vehicle type (VEHTYP) is truck tractor pulling trailer(s).
- Body type (BODTYP) is basic enclosed dry cargo van.
- Single trailer configuration with at least two axles on the trailer (AXLRE codes 14, 16, 18, 19, 20, and 21).

Records in TIUS stratum 5 include tankers, grain hoppers, dump trucks, refrigerated vans, wreckers, beverage trucks, straight trucks, as well as dry vans. Because the shipper survey data included only truck shipments made in enclosed dry cargo trailers, only those TIUS records involving truck tractors pulling such trailers were considered. Single-axle semi-trailers were excluded because they are generally small trailers, usually 28-ft (8.5-m) in length. The assumption was made that any shipper who currently uses small trailers is more likely to switch to a larger sized single trailer before switching to an LCV. The TIUS dataset also contains records for tractors pulling two and even three trailers. These records were also excluded because the shipper survey data did not include any lane observations involving double and triple trailer configurations.

In the second step, each selected vehicle's weight-limited payload was computed using the following formula:

$$\text{Weight-limited payload (lb)} = \text{MAXWGT} - \text{EMPWGT} \quad (1)$$

In the third step, each selected vehicle's cube-limited payload weight was computed as two-thirds of the weight-limited payload weight. Analysis of the shipper survey data revealed that the average payload of cube-limited shipments was two-thirds the average payload of weight-limited shipments (the actual factor was 0.6615).

The fourth step involved estimating the vehicle's annual weight-limited ton-mileage for trips over 200 mi (322 km) from its home base. The following equation was used:

$$\begin{aligned} \text{Annual weight-limited ton-miles} &= \text{ANNMIL} \times (\text{PLONG} \div 100) \\ &\quad \times (\text{PCARWT} \div 100) \\ &\quad \times (\text{weight-limited payload} \div 2,000) \end{aligned} \quad (2)$$

The vehicle's annual cube-limited ton-mileage for trips over 200 mi (322 km) from its home base was estimated in step 5 from the following formula:

$$\begin{aligned} \text{Annual cube-limited ton-miles} &= \text{ANNMIL} \times (\text{PLONG} \div 100) \\ &\quad \times (\text{PCARSZ} \div 100) \\ &\quad \times (\text{cube-limited payload} \div 2,000) \end{aligned} \quad (3)$$

In step 6, the vehicle's total annual weight-limited and cube-limited ton-mileage were each allocated to each of the following commodity groups according to the percent of the vehicle's annual mileage accounted for while carrying the particular commodity:

- Processed foods and tobacco products (SIC 20 & 21) - PRFOOD.
- Textiles and apparels (SIC 22 & 23) - TEXTIL.
- Lumber and fabricated wood products (SIC 24) - LUMBER.
- Furniture and/or hardware (SIC 25) - FURN.
- Paper and paper products (SIC 26) - PAPER.
- Chemicals and/or drugs (SIC 28) - CHEM.
- Petroleum and petroleum products (SIC 29) - PETROL.
- Plastics and/or rubber products (SIC 30) - PLASTK.
- Building materials, such as gravel, sand, concrete, flat glass, etc. (SIC 32) - BLDGMA.
- Glass products (SIC 32) - GLASS.
- Fabricated metal products (SIC 34) - FABMTL.
- Machinery, including electrical or nonelectrical and electronic (SIC 35 & 36) - MACHINE.
- Miscellaneous products of manufacturing (SIC 38 & 39) - MSCMFG.

Each of these commodity groups was represented by at least four observations in the shipper survey data. The commodity groups that were not included consisted of the following: live animals, fresh farm products, unrefined mining products, logs and forest products, primary metal products, transportation equipment, refuse, industrial water, and hazardous wastes. Another TIUS commodity group excluded from consideration was mixed cargo, which includes small packages. This group was assumed to represent all less-than-truckload (LTL) shipments.

The intramodal diversion model was applied in the seventh step. The ton-mileage diversion percentages shown in table 31 were used to estimate how much of each vehicle's commodity-specific annual weight-limited and cube-limited ton-mileage would be diverted to LCVs under the different GVW scenarios, LCV freight rate assumptions, and minimum

percent cost savings thresholds. The results for each vehicle were then multiplied by the vehicle's expansion factor (EXPFAC) to obtain nationwide estimates for the entire truck population.

In the eighth and final step, the estimates of nationwide diverted ton-mileage were converted to vehicle-miles. This was accomplished by dividing the weight-limited ton-mileage estimates by the average weight-limited payload and the cube-limited ton-mileage estimates by the average cube-limited payload. From the TIUS data the average weight-limited payload was determined to be 47,756 lb (21,681 kg), which was rounded up to 48,000 lb (21,773 kg), and the average cube-limited payload was found to be 31,837 lb (14,441 kg), which was rounded up to 32,000 lb (14,515 kg).

An important assumption in the procedure described above was that, when a truck is neither cube-limited nor weight-limited, there is no incentive to utilize LCVs. Thus, the two key TIUS data fields were PCARSZ, the percent of annual mileage the vehicle carried payloads that filled its maximum cargo size, and PCARWT, the percent of annual mileage the vehicle carried payloads that weighed the maximum cargo weight. The existence of these two data items was the main reason for choosing to use the TIUS dataset despite its serious limitations. Close inspection of the TIUS data, however, revealed that these two percentages were often overlapping. For example, a truck owner may have reported a cube-limited percentage of 75 and a weight-limited percentage of 60. Thus, for 75 percent of its annual mileage the truck was running cube-limited and for 60 percent of its annual mileage it was running weight-limited. Clearly there must have been some overlapping mileage in which the vehicle was operating both cube-limited and weight-limited. There was no easy resolution of this problem except to compute and report diverted cube-limited and weight-limited ton-mileage separately. Each of these estimates by itself understates the total LCV ton-mileage, while the sum of the two overstates it.

ESTIMATED INTRAMODAL DIVERSION

Tables 33 through 36 present the results of the intramodal diversion estimation procedure described in the previous section. The high estimates in these tables are the amount of diversion that would occur if shippers switched to LCVs for any amount of reduction in total logistics cost. The low estimates are the amount of diversion that would occur if shippers switched to LCVs only if the resulting reduction in total logistics cost was at least 25 percent. All the estimates shown in the tables are for 1987. To obtain estimates of diverted vehicle-miles for 1992, the numbers in the tables can be multiplied by a factor representing the growth in truck travel between those two years. Published highway statistics show that the total number of rural truck-miles of travel by tractor-trailer combinations rose from 55,978 million (90,069 million truck-km) in 1987 to 63,984 million (102,950 million truck-km) in 1992.^(9,10) This was an increase of 14 percent. Hence, an appropriate growth factor to apply to the numbers in tables 33 through 36 would be 1.14 to obtain 1992 estimates.

Table 33. Estimated truck vehicle-miles (in millions) diverting to LCVs under existing GVW limits with LCV freight rates same as current single trailer truckload rates.

Commodity Group	Weight-Limited		Cube-Limited	
	Low Estimate	High Estimate	Low Estimate	High Estimate
Processed Foods	225.2	382.9	266.7	472.7
Building Materials	31.9	55.5	35.7	65.4
Lumber & Wood Products	25.8	45.1	27.4	51.1
Paper & Paper Products	154.1	265.0	221.5	400.6
Chemicals	43.7	79.0	34.6	72.3
Petroleum Products	22.2	35.8	14.8	27.1
Plastics & Rubber Products	68.1	120.4	85.6	167.4
Fabricated Metal Products	34.6	58.2	51.0	89.0
Machinery	18.9	34.7	26.0	50.6
Furniture & Hardware	65.1	115.9	138.1	242.8
Glass Products	29.4	52.6	49.4	96.2
Textiles & Apparels	50.7	88.0	92.2	163.8
Misc. Manufacturing Products	83.8	138.9	95.2	179.3
Totals	853.5	1,472.0	1,138.1	2,078.4
	21 %	36 %	28 %	51 %

Metric conversion: 1 vehicle-mi = 1.609 vehicle-km

Table 34. Estimated truck vehicle-miles (in millions) diverting to LCVs under existing GVW limits with LCV freight rates higher than current single trailer truckload rates.

Commodity Group	Weight-Limited		Cube-Limited	
	Low Estimate	High Estimate	Low Estimate	High Estimate
Processed Foods	138.8	378.3	170.0	463.6
Building Materials	20.0	54.5	23.4	63.9
Lumber & Wood Products	16.2	44.3	18.2	49.6
Paper & Paper Products	96.2	261.8	145.4	394.2
Chemicals	28.0	76.8	25.0	68.6
Petroleum Products	12.8	35.3	9.7	26.4
Plastics & Rubber Products	43.3	118.2	59.4	161.8
Fabricated Metal Products	20.9	57.3	32.0	87.4
Machinery	12.3	33.7	17.8	48.7
Furniture & Hardware	42.0	114.1	88.5	239.9
Glass Products	18.7	51.2	34.0	92.8
Textiles & Apparels	31.5	86.1	59.0	160.8
Misc. Manufacturing Products	49.9	136.9	64.2	174.7
Totals	530.7	1,448.4	746.5	2,032.4
	13 %	36 %	18 %	50 %

Metric conversion: 1 vehicle-mi = 1.609 vehicle-km

Table 35. Estimated truck vehicle-miles (in millions) diverting to LCVs under higher GVW limits with LCV freight rates same as current single trailer truckload rates.

Commodity Group	Weight-Limited		Cube-Limited	
	Low Estimate	High Estimate	Low Estimate	High Estimate
Processed Foods	299.9	382.9	357.7	472.7
Building Materials	42.7	55.5	48.0	65.4
Lumber & Wood Products	34.7	45.1	37.2	51.1
Paper & Paper Products	205.1	265.0	294.6	400.6
Chemicals	59.4	79.0	48.5	72.3
Petroleum Products	29.9	35.8	20.0	27.1
Plastics & Rubber Products	91.4	120.4	116.6	167.4
Fabricated Metal Products	46.4	58.2	68.4	89.0
Machinery	25.6	34.7	35.7	50.6
Furniture & Hardware	86.6	115.9	183.0	242.8
Glass Products	39.9	52.6	67.5	96.2
Textiles & Apparels	68.3	88.0	123.5	163.8
Misc. Manufacturing Products	112.4	138.9	128.4	179.3
Totals	1,142.3	1,472.0	1,529.1	2,078.4
	28 %	36 %	38 %	51 %

Metric conversion: 1 vehicle-mi = 1.609 vehicle-km

Table 36. Estimated truck vehicle-miles (in millions) diverting to LCVs under higher GVW limits with LCV freight rates higher than current single trailer truckload rates.

Commodity Group	Weight-Limited		Cube-Limited	
	Low Estimate	High Estimate	Low Estimate	High Estimate
Processed Foods	248.2	376.9	294.6	461.0
Building Materials	35.3	54.3	39.2	63.4
Lumber & Wood Products	28.7	44.0	30.5	49.2
Paper & Paper Products	169.0	260.8	238.9	392.4
Chemicals	49.3	76.1	39.7	67.5
Petroleum Products	25.4	35.2	16.4	26.2
Plastics & Rubber Products	75.3	117.5	94.6	160.2
Fabricated Metal Products	38.8	57.0	56.6	86.9
Machinery	21.2	33.4	29.3	48.1
Furniture & Hardware	70.7	113.6	149.2	239.1
Glass Products	33.2	50.8	55.1	91.8
Textiles & Apparels	56.9	85.6	101.5	159.9
Misc. Manufacturing Products	94.5	136.3	104.3	173.4
Totals	946.4	1,441.6	1,249.8	2,019.2
	23 %	35 %	31 %	50 %

Metric conversion: 1 vehicle-mi = 1.609 vehicle-km

The percentages appearing at the bottom of tables 33 to 36 were based on an estimated total truck-mileage of 4,063.2 million (6,537.7 million truck-km) in 1987. This total was derived from the TIUS records selected in the diversion estimation procedure. It represents the number of miles operated by truck tractors pulling single enclosed dry van semi-trailers with at least two axles while hauling one of the 13 selected commodity groups on trips at least 200 mi (322 km) long. It accounted for about 22 percent of the 18,667.4 million long-range truck-mi (30,035.8 million truck-km) made in 1987 for the 13 selected commodity groups for all body types and combinations of tractor-trailers.⁽¹¹⁾ In turn, the total long-range truck-mileage for the 13 commodity groups comprised about 49 percent of the 38,383 million long-range truck-mi (61,758.2 million truck-km) made in 1987 for all truck-tractors hauling any kind of commodity, including mixed cargo, in any kind of body type and configuration of trailers.⁽¹¹⁾

The estimates of nationwide intramodal diversion to LCVs ranged from 0.5 billion to 1.5 billion truck-mi (0.8 billion to 2.4 billion truck-km) for weight-limited freight and from 0.75 billion to 2.1 billion truck-mi (1.2 billion to 3.4 billion truck-km) for cube-limited freight. As mentioned earlier in this chapter, there was an undetermined amount of overlap between the weight-limited and cube-limited truck mileage so that adding the two estimates would likely overstate the amount of diversion.

The broad range of estimated nationwide intramodal diversion indicates the significant extent to which such factors as GVW limits, LCV freight rates relative to single trailer truckload rates, and minimum required cost savings can affect the amount of diversion that might occur. For example, going from existing GVW limits to higher limits more suited to LCVs could divert an additional 288.8 million truck-mi (464.7 million truck-km) if LCV freight charges were the same as single trailer truckload rates. The significance of how much reduction in total logistics cost would be required to induce shippers to use LCVs is reflected in the differences between the high and low estimates, which ranged from 329.7 million truck-mi (530.5 million truck-km) to 1,285.9 million truck-mi (2,069.0 million truck-km), depending on the GVW limit and LCV freight rate scenario. Whether or not the estimates are realistic is impossible to determine, but they do show a great deal of sensitivity to factors which are difficult to determine.

COMPARISON WITH OTHER ESTIMATES

One way to gauge the reasonableness of the above estimates is to compare them with estimates of intramodal diversion from other studies. Such comparisons are burdened with their own inherent difficulties because of differences in types of LCVs considered, assumptions about LCV operating costs and productivity, assumed GVW limits, estimation methodology, assumptions about shipper and carrier acceptance of LCVs, sources and quality of data, and so on. In the end, all projections of nationwide LCV use are purely speculative. Consequently, the only comparison made was with estimates developed in a recent Transportation Research Board (TRB) study.⁽³⁾

The TRB study analyzed four prototype truck-trailer configurations with lower axle weights but higher than currently allowed gross weights in accordance with a proposal advanced by former Federal Highway Administrator Francis C. Turner. The four Turner prototypes considered in the study consisted of a seven-axle tractor-semitrailer combination, nine- and eleven-axle double trailer configurations, and a nine-axle B-train double trailer combination. These prototypes were analyzed in terms of their effects on pavement wear, bridge costs, safety, traffic operations, freight costs, productivity, and use.

The market for the double-trailer prototypes was divided into a number of sectors defined by trailer body type, private versus for-hire carrier, and local versus intercity travel. The various body types included dry vans, reefers, flatbeds, dry bulk trailers, and tankers. Dry vans were further segmented into less-than-truckload and truckload shipments and the latter were further divided into low-density and high-density commodity groups. A market potential of low, moderate, or high was assigned to each of these sectors, based on a review of past projections of LCV usage, estimates of the costs of the Turner prototypes, interviews with carriers, and current use of multiple trailer configurations. Each market rating was then quantified as follows:

- A low market potential meant a 10 percent potential shift of traffic to Turner prototypes.
- A moderate market potential corresponded to a potential 33 percent shift.
- A high market potential entailed a potential 67 percent shift.

These diversion rates were then applied to current vehicle-miles of travel by 5-or-more axle tractor-semitrailers, 5-axle truck-trailers, and 5- and 6-axle double trailers in each market sector. The total number of vehicle-miles of travel for all combination trucks was taken from the *1987 Highway Statistics* publication. This total was distributed among the various market segments based on data from the 1982 TIUS, adjusted to account for the increased use of twin trailer combinations between 1982 and 1987.

Of the many market sectors identified in the TRB study, only the ones involving intercity truckload shipments in dry vans closely matched the market sectors considered in the current study. The TRB study assessed the market potential of each of these sectors as follows:

- The private carrier, intercity, dry van, low-density truckload market potential was rated as low to moderate.
- The for-hire carrier, intercity, dry van, low-density truckload market potential was rated as low.

- The private carrier, intercity, dry van, high-density truckload market potential was rated as moderate.
- The for-hire carrier, intercity, dry van, high-density truckload market potential was rated as moderate.

The TRB study's estimates of traffic diversion to Turner prototypes in each of the intercity dry van truckload market sectors are shown in table 37. For comparison with tables 33 through 36, low density freight may be regarded as cube-limited and high density freight as weight-limited. In comparing the TRB study's results with the estimates made in the current study, it is more correct to use only tables 35 and 36 which cover the high weight capacity scenario.

Table 37. Estimated billions of truck miles diverting to Turner prototypes in the intercity dry van truckload market sectors.⁽³⁾

Type of Carrier	Type of Freight		Total
	Low Density	High Density	
Private	0.3 - 1.0	2.2	2.5 - 3.2
For-hire	0.4	2.3	2.7
Total	0.7 - 1.4	4.5	5.2 - 5.9

Metric conversion: 1 truck-mi = 1.609 truck-km

The TRB study estimated between 0.7 and 1.4 billion truck-mi (1.1 to 2.3 billion truck-km) would divert to Turner prototypes in the low density intercity truckload freight sectors. This overlapped the bottom of the range of 1.2 to 2.1 billion truck-mi (1.9 to 3.4 billion truck-km) of diverted cube-limited freight estimated by the current study under the high weight capacity scenario. On the other hand, the TRB study's estimate of 4.5 billion truck-mi (7.2 billion truck-km) of high density freight diverting to Turner prototypes was three times higher than the highest estimate of diverted weight-limited truck mileage in the current study.

One reason for the large difference in the estimates of diverted weight-limited freight was the fact that the TRB study's estimates were based on a total truck mileage of 20.4 billion (32.8 billion truck-km) compared to 4.1 billion truck-mi (6.6 billion truck-km) in the current study. Unlike the current study, the TRB study considered not only diversion from single trailer truckload shipments but twin trailer shipments as well. The TRB study also did

not exclude any commodity groups. Consequently, a better measure of comparison between the two studies is the estimated market shares.

The TRB study estimated that 11 percent to 21 percent of the total truck-miles of intercity low density dry van truckload traffic would divert to LCVs, compared to an estimated range of 31 to 51 percent in the current study. The much lower market share in the TRB study reflects that study's assessment of the market potential of the low density dry van truckload sectors as low to moderate. For the high density market sectors, whose market potential was rated as moderate, the estimated market share was 33 percent, compared to a range of 23 percent to 36 percent estimated by the current study. Thus, a major difference between the results of the two studies was due to the TRB study's low assessment of the LCV market potential of low density or cube-limited truckload freight traffic.

6. CONCLUSIONS

The underlying purpose of this study was to examine the issue of LCV usage from the standpoint of the individual firm or shipper rather than from the viewpoint of the motor carrier or truck operator. This approach was quite different from that of previous studies, which have often focussed on the fixed and variable costs of operating LCVs and the potential gains in productivity which these truck configurations may offer to the carrier. Based on these expected gains in carrier productivity, previous studies have predicted significant savings in freight costs for shippers. Freight costs, however, comprise only a portion of the shipper's total logistics cost which also includes the cost of carrying inventory. If by switching from single trailer truckloads to LCVs, a shipper's inventory carrying costs increase more than any savings in transportation costs, then any productivity gains available to the carrier will be lost to the shipper. The basic intent of the current study was to determine the effects of LCVs on the shipper's total logistics cost and how these effects might influence the demand for LCV transport.

A major finding of this study was that, given sufficient flows of a company's product in a lane, LCVs would generally have a positive impact on the total logistics cost of firms that currently ship in single trailer truckload quantities. The actual amount that might be saved was difficult to predict, but on the average, a reduction in total logistics cost between 13 percent and 32 percent could be expected, depending on the type of LCV used, GVW limits, and the difference between LCV and single trailer truckload freight charges. The higher the flow and the longer the lane, the greater the likelihood that LCVs would benefit the truckload shipper. In general, use of LCVs at annual lane volumes below 5,000 cwt (226,795 kg) appears likely to increase a firm's total logistics cost, while at annual lane volumes over 25,000 cwt (1,133,975 kg), LCVs are likely to produce cost savings averaging between 16 percent and 42 percent.

The influence of product value on the cost-effectiveness of LCVs was surprisingly small. The correlation between product value and the percent change in total logistics cost caused by use of LCVs was exceedingly low. The effect of product value was most apparent when the flow of a company's product in a lane was below 15,000 cwt (680,385 kg) or 350,000 ton-mi (510,650 metric ton-km). In such cases, higher product values significantly increased the likelihood that LCVs would greatly elevate the company's total logistics cost. The main effect of product value at moderate and large annual lane volumes was to slightly reduce the average percentage of reduction in total logistics cost resulting from the use of LCVs.

Predicting whether or not the use of LCVs for a given product in a given lane will lower a company's total logistics cost appears to be considerably easier than predicting the actual magnitude of the change. Annual lane volume, lane distance, and annual lane ton-mileage appear to be good indicators of whether or not LCVs will be beneficial. However, none of these variables was highly correlated with differences in total logistics cost between

LCVs and single trailers. Perhaps an even better indicator is the ratio of annual freight costs to annual inventory carrying costs using single trailers in a lane. If the freight costs are two or more times greater than the inventory carrying costs, switching from single trailers to LCVs will in all likelihood greatly reduce the total logistics cost. On the other hand, if the inventory carrying costs are nearly the same as or greater than the freight costs, then the chances are good that switching from single trailers to LCVs will increase the total logistics cost.

The effect of LCVs on the total logistics cost of rail carload shippers was highly sensitive to the rail freight rate per mile. While diversion from rail cars to Rocky Mountain doubles does not appear likely, the results of the analysis indicate that turnpike doubles when operating under higher than existing GVW limits could reduce the total logistics cost enough to induce some shippers to switch from rail to LCVs. Because of the small number of rail observations in the shipper survey data, it was not possible to estimate the amount of diversion that might occur.

Turnpike doubles could also provide some serious competition to rail-truck intermodal services if existing GVW limits were to be raised. The analysis predicted a lower total logistics cost for most of the intermodal shippers in the survey sample as a result of switching to turnpike doubles.

Given the finding that LCVs are likely to reduce truckload shippers' total logistics cost in most cases where traffic lane volumes are moderate to heavy, the more difficult question still to be answered is what effect will this have on the demand for LCV freight services. Will shippers switch from single trailers to LCVs in order to reduce their logistics costs? If so, how much of a cost savings is required before a firm will make the necessary adjustments in its production scheduling and inventory management system to accommodate the higher shipment quantities entailed by the use of LCVs? To what extent is the demand for LCVs influenced by the potential savings in total logistics cost? These are important questions which could not be answered directly in this study. However, it was shown that the level of cost savings necessary to induce diversion from single trailers to LCVs has a tremendous impact on projections of LCV demand.

With regard to the question about the relative importance of logistics cost reduction to the demand for LCVs, a few comments can be made. First of all, it became clear while screening companies for eligibility to participate in the shipper survey that many firms do not consider logistics costs in general or inventory carrying costs in particular when making modal choice decisions. In some cases, particularly for small and even some medium-sized firms, it is because the company did not have a logistics management system sophisticated enough to determine what its inventory and other logistics costs were. In other cases, the companies' product costs and interest rates were so low that they no longer considered inventory carrying costs in making daily transportation decisions. Secondly, there are other ways for a company to reduce its total logistics cost than by switching from single trailers to LCVs. A primary example of this is the current trend toward using the Just-in-Time concept

which trades off inventory and transportation costs by maintaining small inventories, shipping in smaller quantities, and using faster modes of transportation. Therefore, even though this research has shown that LCVs are likely to have a positive effect on shippers' total logistics cost, the trend toward smaller shipment sizes and more rapid on-time deliveries would seem to reduce the demand for LCVs from the standpoint of many shippers.

REFERENCES

1. *Providing Access for Large Trucks*, Special Report 223, Transportation Research Board, National Research Council, Washington, DC, 1989.
2. *Truck Weight Limits: Issues and Options*, Special Report 225, Transportation Research Board, National Research Council, Washington, DC, 1990.
3. *New Trucks for Greater Productivity and Less Road Wear: An Evaluation of the Turner Proposal*, Special Report 227, Transportation Research Board, National Research Council, Washington, DC, 1990.
4. *Evaluating Shipper-Related Productivity Gains to be Achieved from Authorizing Increased Truck Lengths and Gross Vehicle Weights*, Center for Logistics Research, The Pennsylvania State University, University Park, PA, December 1991.
5. Clyde Kenneth Walter, "Longer Combination Vehicles: Issues and User Attributes," *Proceedings of the 35th Annual Meeting*, Transportation Research Forum, New York, NY, October 14-16, 1993.
6. *The Effect of Size and Weight Limits on Truck Costs*, Working Paper, Jack Faucett Associates, Bethesda, MD, October 1991.
7. *1987 Census of Transportation, Truck Inventory and Use Survey: Technical Documentation*, U.S. Department of Commerce, Bureau of the Census, Washington, DC, no date.
8. Patricia S. Hu, Tommy Wright, Shaw-Pin Miaou, Dennis J. Beal, and Stacy C. Davis, *Estimating Commercial Truck VMT of Interstate Motor Carriers: Data Evaluation*, Oak Ridge National Laboratory, Oak Ridge, TN, November 1989.
9. *Highway Statistics 1988*, Table VM-1, Federal Highway Administration, Washington, DC, 1989.
10. *Highway Statistics 1992*, Table VM-1, Federal Highway Administration, Washington, DC, 1993.
11. *1987 Census of Transportation, Truck Inventory and Use Survey: United States*, U.S. Department of Commerce, Bureau of the Census, Washington, DC, 1990.