DHT-1-8-78-231-I

EFFECTS OF HEAVY TRUCKS ON TEXAS HIGHWAYS

RESEARCH REPORT 231-INTERIM

PROJECT 1-8-78-231

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

CENTER FOR HIGHWAY RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

SEPTEMBER 1978

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

Effects of Heavy Trucks on Texas Highways

5. Report Date

September, 1978

6. Performing Organization Code

7. Author(s)

J. L. Brown, D. Burke, F. L. Roberts,
C. M. Walton

8. Performing Organization Report No.

231 - Interim

9. Performing Organization Name and Address

Texas State Dept. of Hwys. & Public Transportation
P.O. Box 5051, Austin, Texas 78763
Texas Transportation Institute, College Station, TX
Center for Highway Research, Austin, TX 78712

10. Work Unit No.

1-8-78-231

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

Texas State Dept. of Hwys. & Public Transportation
P. O. Box 5051
Austin, Texas 78763

13. Type of Report and Period Covered

April - September, 1978

14. Sponsoring Agency Code

15. Supplementary Notes

This report prepared as a cooperative venture between the Texas State Department of Highways and Public Transportation, Center for Highway Research and the Texas Transportation Institute.

16. Abstract

The objective of this study was to assess the effects of projected truck traffic on the highway system of Texas in consideration of the social and economic vitality of the State. The study included the evaluation of the costs and benefits for a twenty-year planning horizon. Alternative scenarios of future truck traffic were assessed. The study did not consider the effects of changes in the size of trucks, only increases in the gross weights and axle loads.

17. Key Words	18. Distribution Statement
Trucks Highway Loading Axle Loads	No restrictions. Report available from the National Technical Information Service; Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	63	

Form DOT F 1700.7 (8-69)

EFFECT OF HEAVY TRUCKS ON TEXAS HIGHWAYS

by

James L. Brown
Highway Design Division
State Department of Highways and Public Transportation

Dock Burke
Texas Transportation Institute
Texas A&M University

Freddy L. Roberts
Center for Highway Research
The University of Texas at Austin

C. Michael Walton
Center for Highway Research
The University of Texas at Austin

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

September 1, 1978

PREFACE

In partial response to Senate Resolution 589 of the 65th Texas Legislature, the State Department of Highways and Public Transportation initiated a study to describe better the relative costs, benefits, and issues surrounding the current and future truck use of Texas highways. This report is a summation of the study scope, methodology, findings, and conclusions of the joint effort performed by the State Department of Highways and Public Transportation (DHT), the Center for Highway Research (CFHR), and the Texas Transportation Institute (TTI).

ACKNOWLEDGEMENTS

Several persons have contributed to the preparation of the study reported herein. The authors would like to express appreciation to the following for their assistance: Larry J. Buttler, H. D. Butler, Robert R. Guinn, Robert L. Reed, Gerald B. Peck, Robert L. Mikulin, Charles R. Davis and John J. Oliver of DHT; Gail Glick of TTI; John Larkin and Farid Rebeiz of CFHR.

Additionally, the authors would like to acknowledge the guidance, direction, and support given to the study by the Size and Weights Committee of DHT. That Committee is composed of the following members:

Chairman - Byron C. Blaschke, Chief Engineer of Maintenance & Operations
R. L. Lewis, Chief Engineer of Highway Design
Wayne Henneberger, Bridge Engineer
Phillip L. Wilson, State Planning Engineer for Transportation
Robert W. Townsley, Director, Motor Vehicle.

James L. Brown
Dock Burke
Freddy L. Roberts
C. Michael Walton

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd) **PAGE**

LIST OF TABLES

TABLE

LIST OF FIGURES

CHAPTER I

EXECUTIVE SUMMARY

OBJECTIVE

The objective of this study was to assess the effects of projected truck traffic on the highway system of Texas in consideration of the social and economic vitality of the State.

SCOPE

The study included the evaluation of the costs and benefits for a twenty-year planning horizon. Alternative scenarios of future truck traffic were assessed. *The study did not consider the effects of changes in the size of trucks,* only an increase in the gross weights and axle loads. The study did not evaluate the effects that heavy trucks would have on county roads or city streets.

GENERAL METHODOLOGY

The study was organized into three phases:

- The establishment of current and future truck traffic distributions that will most likely occur on the state highway system for each of two conditions or scenarios. The first, Scenario A, was evaluated as the conditions that will develop under the present weight law of a gross weight of 80,000 pounds. (Max. Single Axle Load = 20,000 lbs. and Max. Tandem Axle Load = 34,000 lbs.) The second, Scenario B, was evaluated as the conditions developing under a possible future legal weight increase to a gross vehicle weight (GVW) of 120,000 pounds. (Max. Single Axle Load = 26,000 lbs. and Max. Tandem Axle Load = 44,000 lbs.) *This weight was suggested in a Federal Highway Administration study (Ref. 1).* Also, the 120,000 pound GVW represents a maximum likely change and is sufficiently large that estimated results would not be overwhelmed by data inaccuracies. Figure 1-1 schematically shows the maximum legal loading condition of the four trucks used to represent both scenarios. Figure 1-2 shows the percentages of these trucks on the highways. Both scenarios considered distributions of all trucks including overloads.

- An evaluation was made of the comparative tax dollar costs required to perpetuate the state highway system in an acceptable condition while carrying the traffic estimated for both scenarios. The basis for this evaluation was the general finding from the AASHO Road Test (Ref. 9) that showed that heavier axle loads cause pavements to deteriorate at an accelerated rate. Figure 1-3 shows a typical relationship between the heavier axle loads and the equivalent damage as represented by an 18,000-pound single axle load (18 KSAL). The additional costs for Scenario B were obtained by subtracting the cost of Scenario A from Scenario B.

- An evaluation was made of the incremental benefits associated with the variation in conditions inherent in the Scenarios A and B. The benefits as defined in this study are associated with the increased payloads of Scenario B over Scenario A.

DATA LIMITATIONS

The Scope and General Methodology described above were incorporated to direct the study which proceeded under the limited time available. A primary implication of this time constraint was the definition of a data base sufficient to conduct the analysis. Limitations on the data base were three types:

- Existing data to describe current traffic, truck costs, and highway inventory were used. None of these data were both complete and current and, consequently, may contain inaccuracies.

- No statewide data were available for an analysis of heavier trucks operating on city streets and county roads in Texas.

- Structure related costs were limited to upgrading current structurally deficient bridges to carry the loadings of the two scenarios. The lack of definitive data restricted the inclusion of bridge maintenance and rehabilitation costs associated with truck loadings. Furthermore, the lack of technology regarding the effects of heavy loading and frequency on bridge deterioration has limited the evaluation of differential bridge rehabilitation and replacement costs.

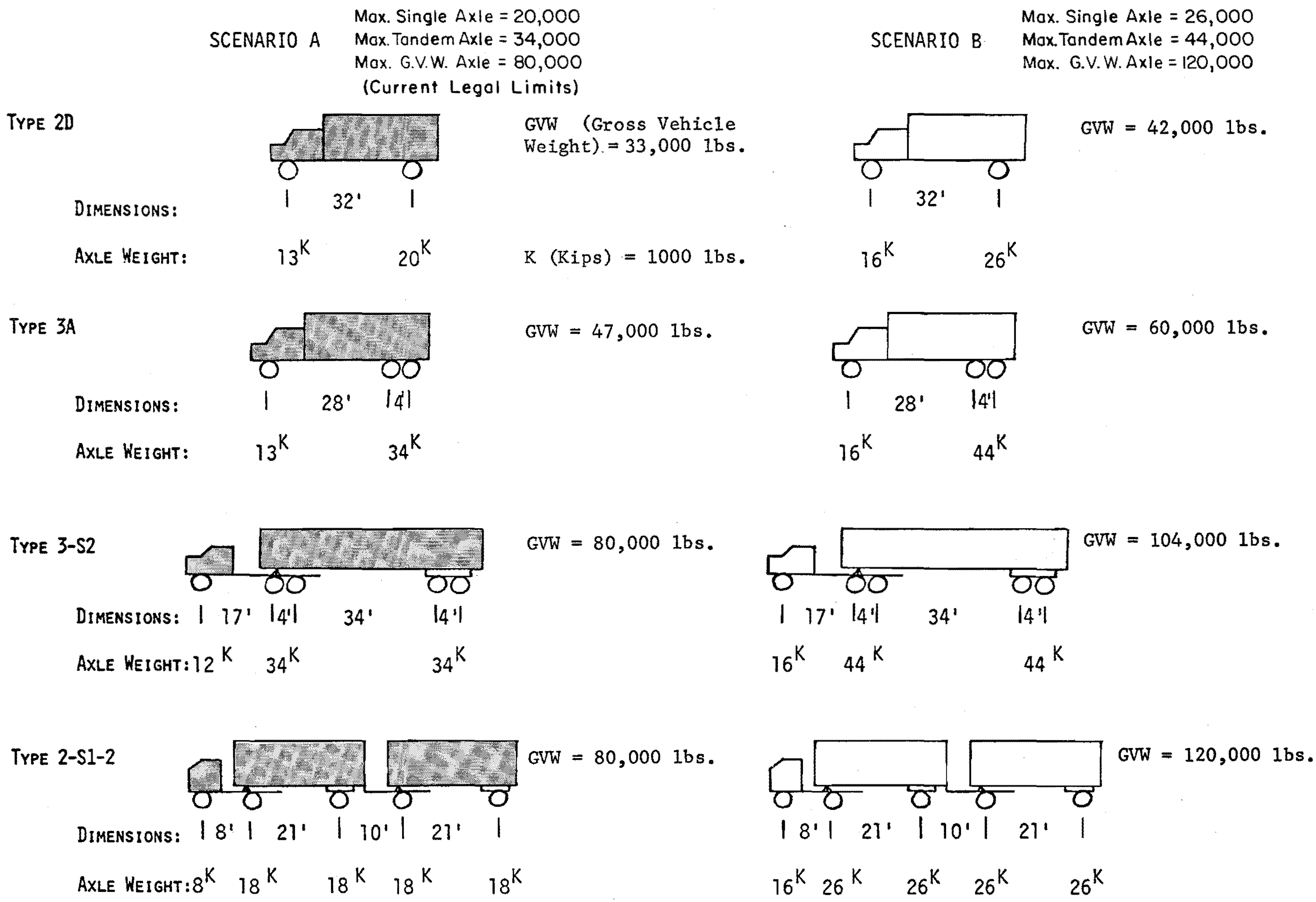


Figure 1-1 Selected Truck Configurations for Scenarios A and B

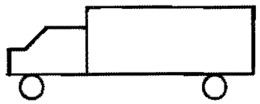
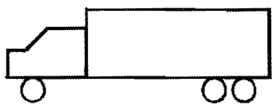
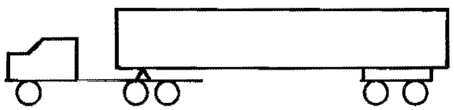
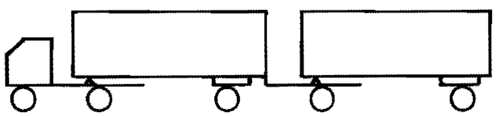
TRUCK TYPE		HIGHWAY TYPE			
		INTERSTATE HIGHWAYS	FARM TO MARKET ROADS	OTHER STATE HIGHWAYS	CITY STREETS / COUNTRY ROADS
2D		8%	23%	11%	Unknown
3A		3%	18%	7%	Unknown
3-S2		84%	59%	80%	Unknown
2-S1-2		5%	0%	2%	Unknown

Figure 1-2 Distribution of Selected Trucks by Highway Types

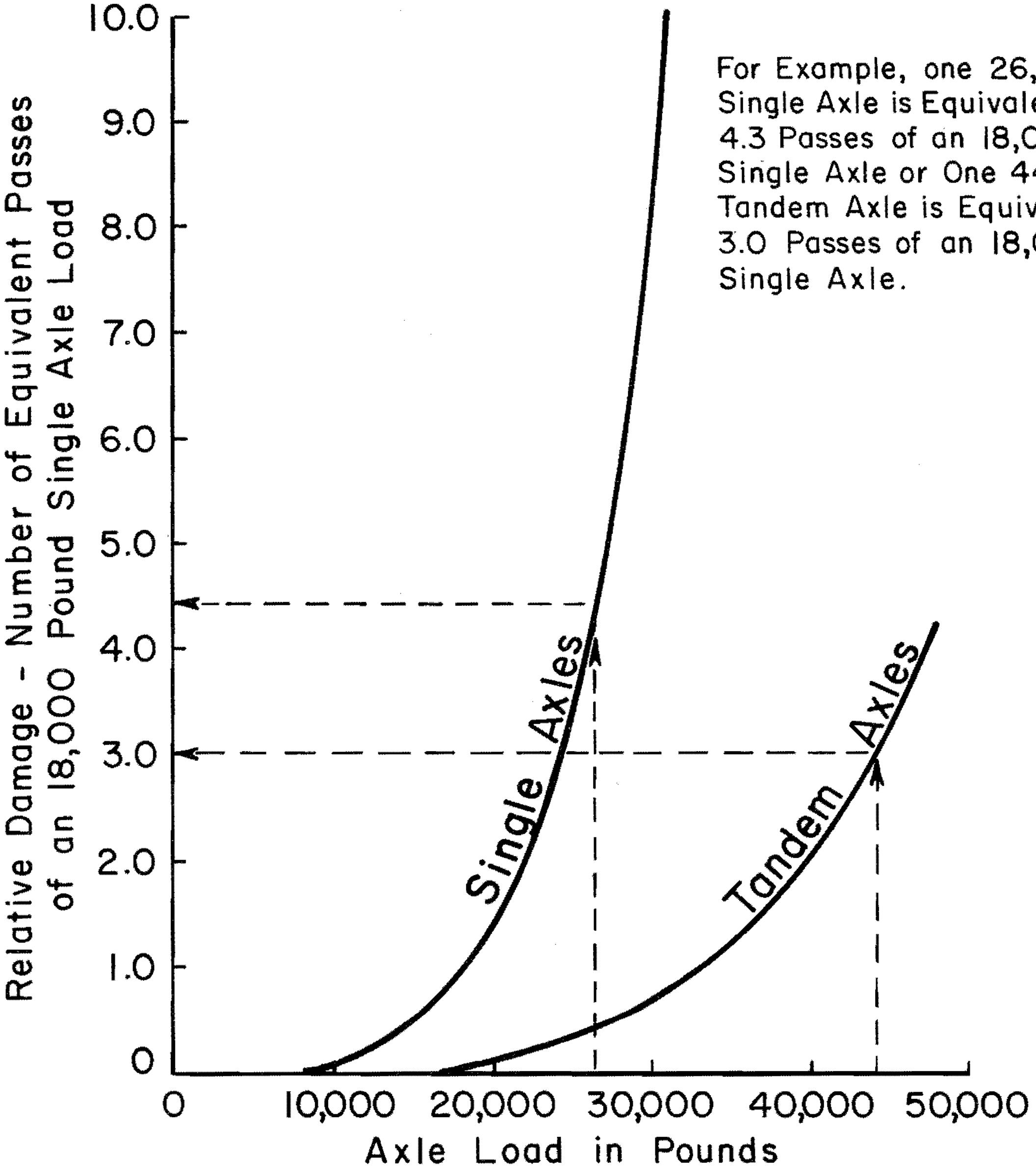


Fig. 1-3 Typical Relative Damage Caused by Different Sized Axles – from the AASHO Road Test

FINDINGS AND CONCLUSIONS

The differential costs between Scenario A and B associated with heavier truck loads (subject to the limitations listed on page 2) and the corresponding savings in truck operating costs for the 20-year analysis period are presented in the following table:

	Total for Hwy Systems	Interstate Highways	FM Roads	Other State Hwys	Co. Roads & City Streets
Add'l Hwy Costs (in billions of constant 1977 dollars)	3.50	.72	.74	2.04	unknown
Savings in Truck Operating Costs (in billions of constant 1977 dollars)	9.12	4.57	.71	3.84	unknown
Fuel Savings* (in billions of gallons)	2.42	1.21	.18	1.03	unknown

Figure 1-4 shows the total costs for the various classes of highways.

From the above data, it appears that if weight law changes are undertaken, further analysis would be justified to select those routes that would carry relatively large freight tonnages and would cost relatively less to upgrade.

Figure 1-5 shows the cost to maintain the existing system for both Scenario A and B on an annual basis. From the data in Figure 1-5 it can be inferred that once the highways have been upgraded to handle the heavier trucks, the additional cost to maintain the system for the heavier trucks will decrease. In other words, the additional costs beyond 1997 would be less than those costs occurring during upgrading.

Due to the current interest in the energy situation, a separate analysis was conducted to examine what, if any, fuel savings might result from an increase in truck weights. These calculations indicate that fuel saved would be about 1.8 percent of that needed to haul the same amount of truck freight under the present weight law.

*Fuel cost savings are included in Savings in Truck Operating Costs

Additional analyses were completed in an attempt to relate vehicular pollution and changes in vehicle weights. For the three major Texas metropolitan areas (Dallas-Ft. Worth, Houston-Galveston, and San Antonio), a decrease representing less than a 1 percent reduction in pollution generated by all urban transportation was computed. The available data and research on noise pollution indicated that the hypothesized increases in axle weight limits should generate only small increases in noise along highways.

OTHER CONSIDERATIONS

The major approach to this study involved the estimation of the comparative maintenance and rehabilitation costs of perpetuating the state highway systems under current weight limitations and on future use under different weight conditions. *These costs were based on alternative weight limitations on truck use and did not consider size alternatives.* An increase in the size of vehicles has significant ramifications beyond the scope of this study and is mentioned only to enable a better appreciation of the limitation implicit in these findings.

Many significant considerations are involved with both size and weight changes in truck usage that were not considered explicitly in this study. These include, but are not limited to, the following:

- geometric design and redesign and construction of streets and highways to accommodate larger trucks, e.g., longer and wider vehicles resulting in modification in lane, median and shoulder widths, passing lanes, turning radii at curves and intersections, signing, safety rest-stops, right-of-way requirements, etc.;
- highway safety considerations reflecting a more diverse mix of vehicles traveling on the highways, e.g., larger, longer or heavier trucks mixed with increasingly smaller automobiles create significant safety issues which may be translated into higher accident rates and a corresponding increase in accident severity;
- other highway operational implications such as wet weather conditions (splash and spray), oversize vehicles, hazardous loads, etc.;
- costs of replacing bridges and pavements on county roads, city streets, private driveways, and parking terminals;
- additional costs of the construction of pavements and bridges to accommodate heavier loads on new locations;
- accelerated bridge deterioration related to heavier and increased frequency loadings is known to occur but cannot be quantified with current technology.

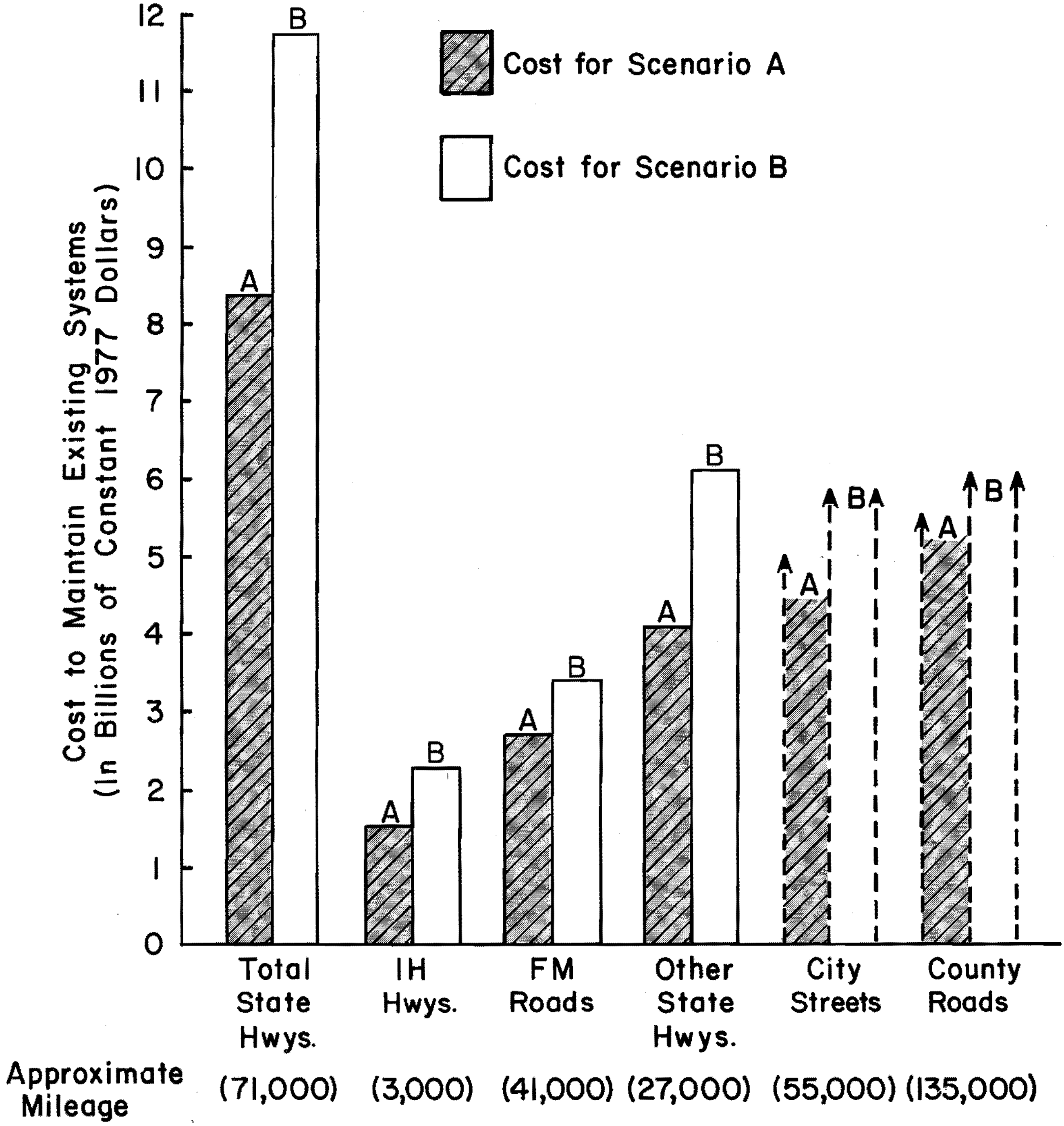


Figure 1-4 TWENTY-YEAR COST (1977-1997) TO MAINTAIN EXISTING SYSTEMS*

* Bridge costs included in totals only reflect expense of upgrading structurally deficient bridges to carry the loading of the respective scenarios. Not included are the costs of bridge maintenance, rehabilitation and replacement due to functional deficiencies and deterioration.

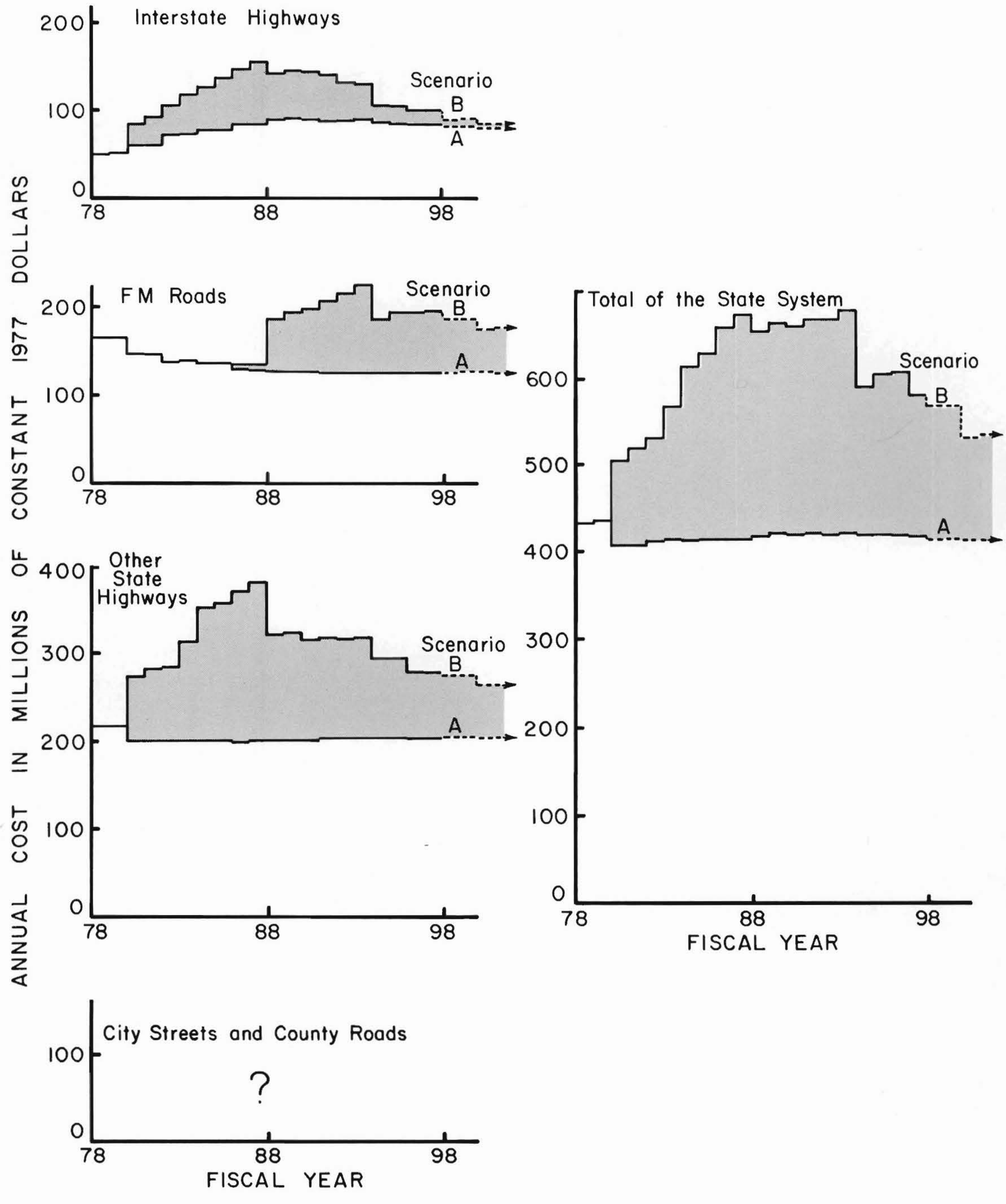


Figure 1-5 COSTS TO MAINTAIN THE EXISTING SYSTEM (Maintenance, Replacement, and Rehabilitation)*

* Bridge costs included in totals only reflect expense of upgrading structurally deficient bridges to carry the loading of the respective scenarios. Not included are the costs of bridge maintenance, rehabilitation and replacement due to functional deficiencies and deterioration.

- implication of new design trucks and performance, such as their acceleration and braking capabilities, and any modifications in truck climbing lanes and downgrade considerations;
- changes in technology in the goods transportation industries; and
- externalities associated with heavier truck loads and the freight shares of rail, pipelines, and waterways due to modal shifts.

DEFINITION OF TERMS

AASHO ROAD TEST - A large scale road test sponsored by the American Association of State Highway Officials (AASHO is now the American Association of State Highway and Transportation Officials or AASHTO.) One of its main objectives was the determination of the effects of various axle loads upon pavements.

CENTER FOR HIGHWAY RESEARCH - An administrative unit created in the College of Engineering in 1963 to represent the University of Texas at Austin in all matters related to highway research. Through the Center, the unique resources of faculty, students, staff, and facilities at the University are brought to bear on technical, economic, environmental, and societal problems of transportation in Texas and around the nation.

18,000 POUND EQUIVALENT SINGLE AXLE LOAD (18 KSAL) - A standard axle size against which all other single or tandem axles can be equated in terms of the damage done to pavements.

GROSS VEHICLE WEIGHT (GVW) - The total weight of a truck including its cargo.

MODAL SHIFT - A change in the mode of shipment for a commodity such that proportionately more (less) of that commodity is carried by one mode (or modes) at the expense of another mode or modes.

MODES OF TRANSPORTATION - Ways in which freight is moved from one point to another. Common modes include highways, pipelines, waterways, airlines, and railroads.

OVERLOADS - Those truck trips that are made with loads exceeding the legal weight limits, either axle or gross limits.

SCENARIO - An account or synopsis of a projected course of action or events.

SENATE RESOLUTION 589 - A resolution authored by Senator Schwartz and passed by the Texas Senate during the 64th Legislature requiring that a report describing the planning system being used by the State Department of Highways and Public Transportation be submitted to the 65th Legislature.

SIZE AND WEIGHTS COMMITTEE - An internal working committee of the State Department of Highways and Public Transportation charged with monitoring all changes, both proposed and accomplished, in size and weight legislation that may affect Departmental operations.

TEXAS TRANSPORTATION INSTITUTE - The Texas Transportation Institute, established in 1950 as a part of Texas A&M University, provides research services to public agencies and private firms and has been designated as an official research agency of the Railroad Commission of Texas, the Texas Aeronautics Commission, and the State Department of Highways and Public Transportation.

TRUCK OPERATING COSTS - All costs, exclusive of highway user taxes, associated with owning and operating a truck. Costs include depreciation, fuel, labor, and maintenance.

CHAPTER II

CURRENT AND FUTURE TRUCK USE OF HIGHWAYS

This phase of the study involved two major components: (1) review and evaluation of prior studies, literature, and pertinent material, and (2) identification of alternative scenarios considered to be reasonable possibilities from which 20-year forecasts could be made of truck use of Texas highways. The output of this phase of the analysis was used in the computation of the costs and benefits presented in subsequent chapters of this report.

SCENARIO SELECTION

The identification of alternative scenarios that served in the development of the 20-year forecasts was accomplished through sessions of analysis, discussion, and evaluation of both the existing axle limits and those used in a Federal Highway Administration Study (Ref. 1) as well as those that might be likely candidates for the near future. It was decided that, for this limited study, the indication of the effects of increased truck weights could best be evaluated by considering two scenarios. Scenario A would include the continued application of existing law on weights and sizes. Scenario B would include increasing the maximum allowable weights on axles to that recommended by the Federal government but would retain the present restrictions on the size of vehicles.

Four different types of trucks were selected as the most representative of the existing and future fleet of trucks that will be operating on Texas highways. Schematic diagrams of each of the vehicles, along with the maximum legal axle loads considered for each of the two scenarios, were shown previously on Figure 1-1.

The following vehicular dimension restrictions, which represent the present law, were considered applicable for both scenarios:

Maximum length: 45 feet for single unit trucks
65 feet for trailer and semi-trailer combinations.

Maximum width: 96 inches.

Under Scenario A, using the existing Texas law, both the axle loads and spacings were restricted through the use of a Bridge Formula which limits both axle loads and configurations for the purpose of protecting bridges from excessive damage by loads from trucks (Ref. 2). Under Scenario B, a similar protection of bridges was provided by keeping the identical axle spacing.

PROJECTED TEXAS TRUCK TON-MILEAGE

To facilitate the forecast of truck types, their assignment to highway classes and trip lengths, a projection of future truck ton-miles in the State of Texas from 1977 to 1997 was required. The total projection was divided into two major categories: intercity and urban. The intercity ton-mileage was allocated to three functional highway classes: Interstate, Farm-to-Market Roads, and Other State Highways. Likewise, the urban figures were allocated to three functional classes of highways: Interstate, other State freeways and arterials, and collectors. Figure 2-1 depicts the 1977 to 1997 forecast, and Figure 2-2 shows the 1997 allocation of ton-mileage to various highway types. The forecasted ton-mileage was assumed to remain constant in both scenarios.

COMPUTATIONAL PROCEDURES

To illustrate the basic procedure, the following discussion of how the truck population is likely to be affected by a change in the maximum legal GVW is offered. First of all, there will be more trucks operating above the current legal limit (80,000 pounds). These will be replacing some trucks that had been operating near and below the old limit. As a result of the shift, ton mileage remaining constant, there will be an overall reduction in the number of loaded vehicle trips and, correspondingly, a decrease in the number of empty trips.

At the same time, there will be a portion of the truck population that is unaffected by the change in maximum legal GVW. The loads on these trucks are either low density commodities (volume constrained) or partial loads (demand constrained).

The actual procedure used in the computations was obtained from a National Cooperative Highway Research Program (NCHRP) study of truck sizes and weights (Ref. 3). This NCHRP model was modified and adapted for use in the present study (see Appendix). Truck operating costs, fuel consumption, and 18 KSAL were calculated for each scenario.

The procedure used data collected by the State Department of Highways and Public Transportation over the past 20 years (Ref. 4). The data represents vehicle (empty and loaded) weight intervals sampled at designated highway locations around the State. The

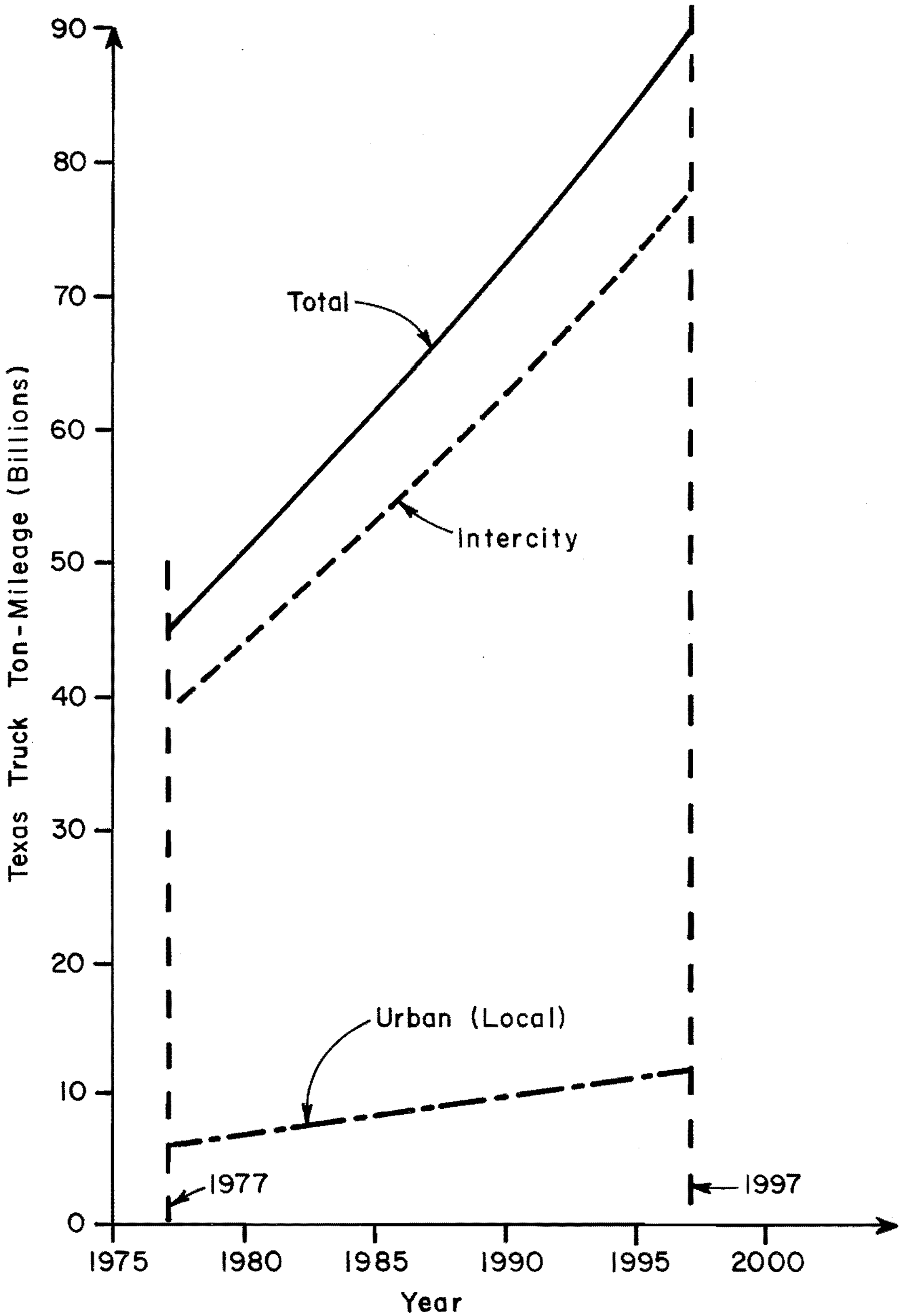


Figure 2-1 Projection of Texas Truck Ton-Mileage Including Intercity-Urban Split

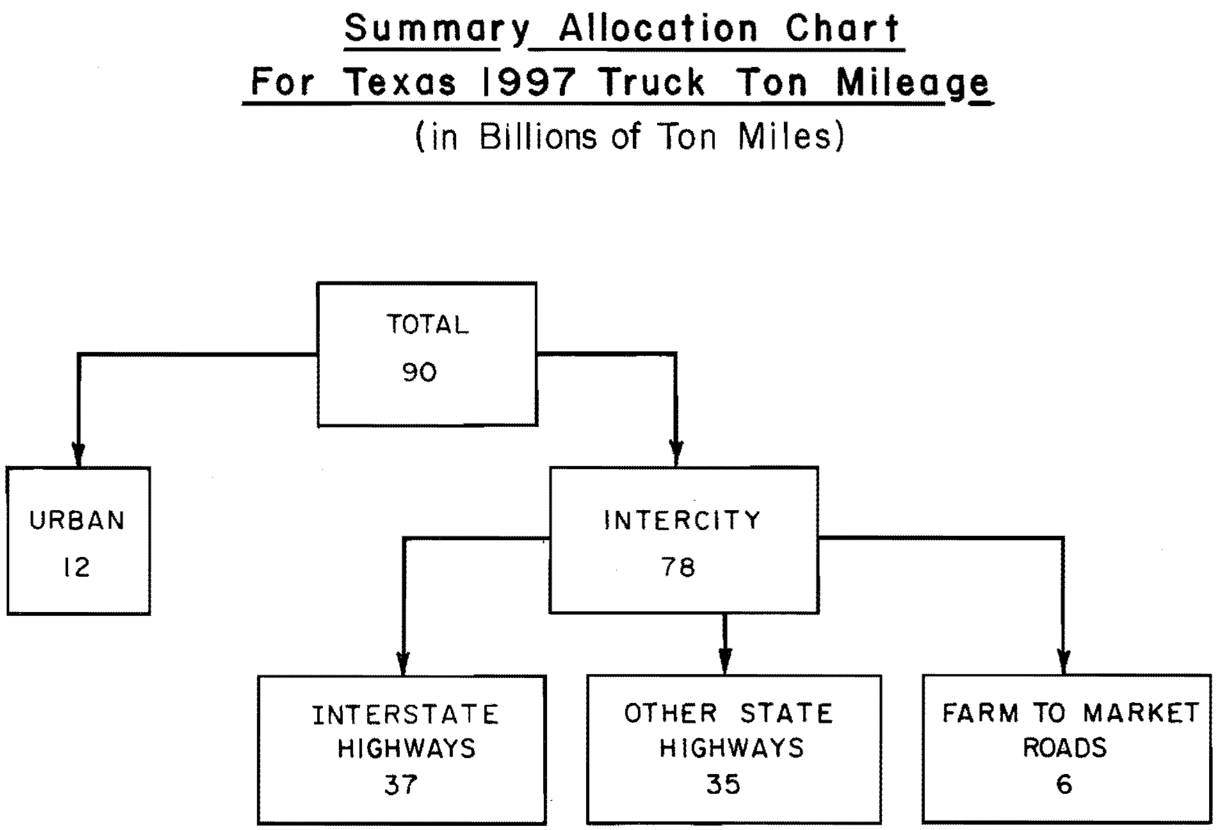


Figure 2-2 Summary Allocation Chart for Final 1997 Texas Truck Ton – Mileage

information, therefore, is classified by highway classes and vehicle types in addition to weight information. The distribution of gross weights for specific classes of trucks under existing legal limits was established from the above information.*

The process required the development of a technique for computing the average empty vehicle weights, the average pay load carried, and the 18 KSAL for each vehicle type and each highway system.

The number of 18 KSAL, truck operating costs, and fuel consumption for each highway class for each year over the forecast period (20 years) were calculated by using the truck freight ton-mile allocation for each class, the average pay load per mile of a system for each year, and the total number of vehicles required to carry the freight allocated to that vehicle type. The process was repeated for each of the two scenarios. The 18 KSAL output was used as input into SDHPT programs for computing the impact on highway maintenance and rehabilitation. The truck operating costs and fuel consumption data were used as input to the evaluation of benefits.

IMPLEMENTATION OF SCENARIOS A AND B

At present, there are approximately 24,000 miles of FM Roads and 900-plus bridges load zoned to less than the vehicle weights considered for Scenario A. Scenario A was analyzed as if no load zone restrictions existed. This approach was selected since the existing load zoned facilities are almost exclusively on the Farm to Market Road System and therefore impact truck usage to a lesser degree.

A comparison of the weights of trucks proposed in Scenario B with the allowable truck weights on the bridges on the current network of highways as described in Chapter III revealed that a significant number of the bridges would require restrictive load zoning until replacement if the load limit laws were increased. The over loading in Scenario B is so great that this load zoning would have to be thoroughly enforced to prevent catastrophic failures. For this study it was assumed that the Scenario B law increase would be effective in 1980. As a result of the load restriction on bridges, it was estimated that a 14-year program** of bridge replacements would be necessary to fully implement Scenario B. It

*The available GVW distributions for Texas highways were considered to be representative of trucks operating before the last increase in maximum legal weights had occurred (72,000 GVW max. to 80,000 GVW max.). Therefore, it was necessary to shift the GVW distributions from the previous law to the present law before the computations reported herein were conducted.

**The 14 years was estimated to be "a reasonable" time period to reconstruct these bridges.

was further estimated that a selective replacement scheme could be devised so that 90 percent of the affected freight haul demand would be free to use the heavier trucks within eight years while the remaining 10 percent could use the system by the end of the fourteen years. The highway costs discussed in Chapter III and the trucking industry benefits discussed in Chapter IV were phased in using this fourteen-year transition period beginning in 1980.

CHAPTER III

HIGHWAY COSTS

The general approach used in estimating incremental highway costs to accommodate the heavier trucks of Scenario B was to estimate the costs of only those items of highway maintenance and construction that would be affected by the heavier trucks. The costs of those items were estimated for the next twenty years for both Scenarios A and B.

Costs to maintain the existing network of pavements in good condition for the next twenty years were first estimated (Scenario A). A second estimate was made assuming that the gross weights and axle weights were increased (Scenario B). Included in the pavement costs were routine pavement maintenance, seal coats, and pavement rehabilitation. Also included were the estimated costs of upgrading current structurally deficient bridges to carry the loading of the two scenarios. The cost estimates include neither bridge maintenance, nor bridge rehabilitation and replacement due to functional deficiencies and deterioration. These costs were excluded due to the inability to isolate bridge maintenance requirements associated with heavy loads and the lack of current technology for analyzing the effects of repetitive heavy loadings on the life of structures. Although evaluation technology is not available, it is known that heavier and more frequent loads will accelerate wear-out of bridges. Because pavement deterioration is caused by both truck loading and environmental stresses, the routine maintenance and seal coat costs were assumed to remain constant in both scenarios. This assumption implies that routine maintenance and seal coats are sufficient to handle the environmental deterioration. Pavement rehabilitation costs were estimated to increase with the heavier trucks.

The resulting cost estimates were shown in Figure 1-5. No data were available to estimate the costs of roads and streets off the State system; however, additional costs would be incurred by cities and counties to handle the larger trucks on the city streets and county roads. Table 3-1 contains the costs accumulated for the period Fiscal 1978 through Fiscal 1997 inclusive.

OTHER HIGHWAY CONSTRUCTION COSTS

The largest identifiable highway construction costs, those required for reconstructing pavements due to accelerated wear-out and those associated with replacing load zoned bridges, have been estimated. Other cost increases that are smaller but still significant will be incurred. Estimates for these costs have not been made because of either time limitations or lack of data. Some of these costs fall into the following categories:

- costs of replacing bridges and pavements on county roads, city streets, private driveways, and parking terminals;
- additional costs of constructing new bridges and pavements designed to accommodate the heavier loads;

- costs to provide somewhat flatter grades or more climbing lanes if proportionately more horsepower is not provided with the heavier trucks;

- costs to construct safety features in highways, if superior braking systems are not provided. (Improving the existing highway network to accommodate such trucks to current "safety levels" might prove to be very costly. Among the features possibly needing change are sight distances, median widths, guardrails, and median barriers.)

BASIS FOR PAVEMENT COST ESTIMATES

A computer program entitled REHAB, originally developed in the McKinsey Study (Ref. 5), was improved and used to project the pavement rehabilitation costs. Inputs to this program include the number of lane-miles of pavement, their age, unit costs for rehabilitation, and survivor curves which portray the expected life of the pavements.

The lane-miles and age* data were obtained from files maintained by the SDHPT. Figure 3-1 contains the age distributions of existing lane-miles on each of the state systems. The most recently constructed pavements have been on the Interstate system, followed by the FM system, and the All Other category. Note that there are many non-Interstate lane-miles that have not been rehabilitated or reconstructed in the last twenty years.

Pavement rehabilitation projects vary from simple, thin overlays to major reconstruction. As a general rule, thin overlays will purchase additional life economically but these can be applied only a few times to an existing structure before reconstruction becomes necessary. From the experience of recent years, a realistic mix of such thin overlays and reconstruction projects was estimated for each highway system and each pavement type considered in the REHAB program. Costs for each type of rehabilitation project were estimated using unit prices prevalent in 1977. A proportionate mix of minor and major rehabilitations was used as input to REHAB to represent the proportions of minor and major rehabilitations that are most likely to occur.

*"Age" as defined in this data is the time lapsed since construction, reconstruction, or rehabilitation.

TABLE 3-1 COMPARATIVE TWENTY-YEAR COSTS FOR SCENARIOS A AND B*

	Interstate Highways	Farm-to-Market Roads	Other State Highways	Total State System
	(Millions of Constant 1977 Dollars)			
Scenario A				
Pavement Maintenance & Seal Coats	$ 240	$1,100	$ 960	$ 2,300
Pavement Rehabilitation	1,334	1,512	3,084	5,930
Bridge Replacements *	4*	76*	50*	130 *
Totals	$1,578	$2,688	$4,094	$ 8,360
Scenario B				
Pavement Maintenance & Seal Coats	$ 240	$1,100	$ 960	$ 2,300
Pavement Rehabilitation	1,888	1,953	4,618	8,459
Bridge Replacements*	172*	376*	554*	1,102*
Totals	$2,300	$3,429	$6,132	$11,861

*Bridge replacement costs include only the estimated cost of upgrading existing bridges to carry the loads included in the two scenarios. The cost of structure maintenance, bridge replacement and rehabilitation due to functional deficiencies and wear-out are not included because of the inability to isolate structure maintenance requirements associated with heavy loads and the lack of current technology for analyzing the effects of repetitive heavy loadings on the life of structures. **Therefore the totals do not reflect the entire cost of maintaining the existing system.**

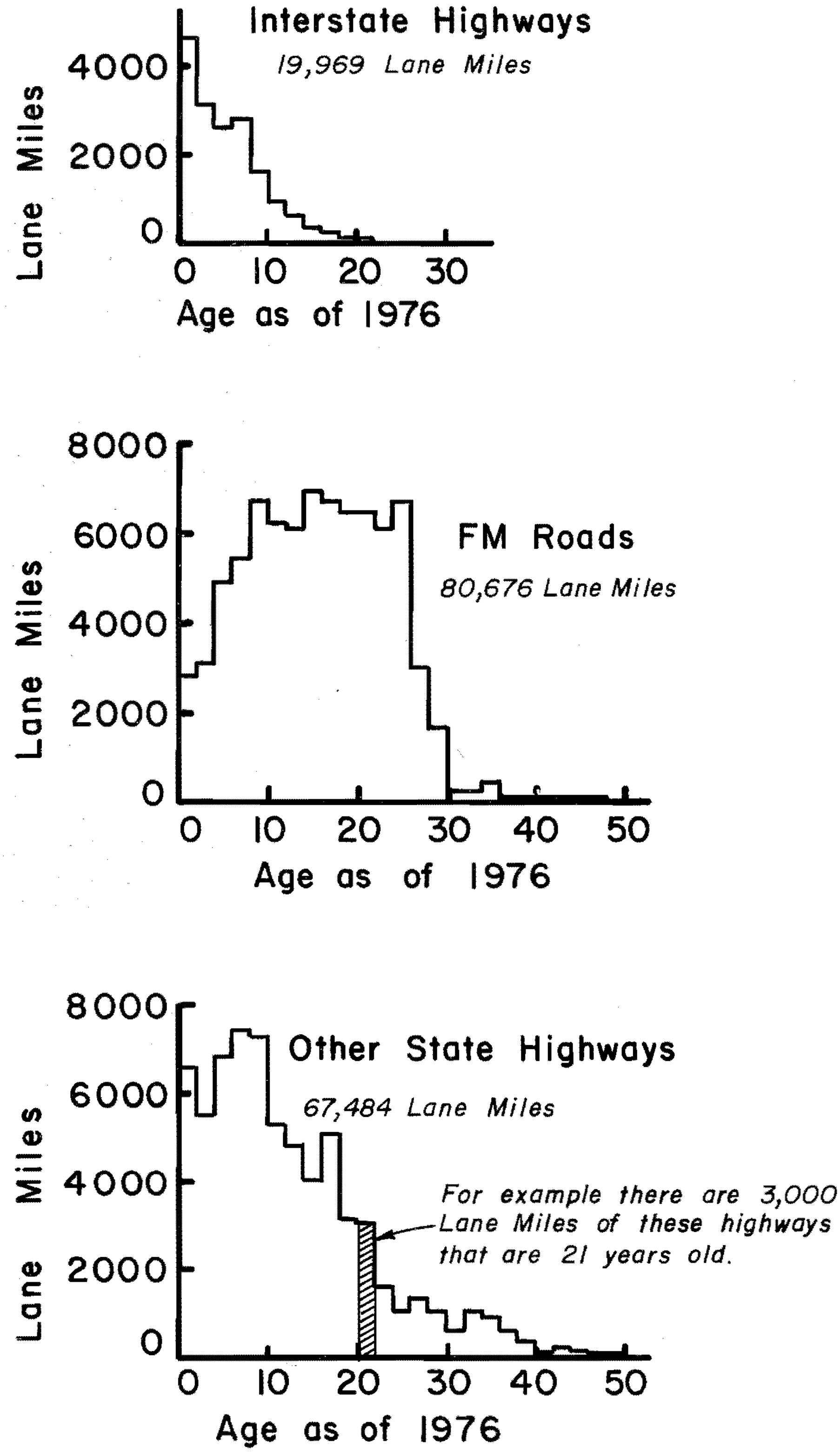


Figure 3-1 AGE DISTRIBUTIONS OF EXISTING LANE MILES

Survivor curves showing the percentage of each pavement type that is expected to survive to a certain age were estimated by a panel of experienced pavement engineers for use by McKinsey and Company when the original REHAB model was developed. These curves were updated for this study using information made available to the panel subsequent to the original estimate. This new data consisted of survivor curves for a sample of pavements obtained both from a research project being conducted by the Texas Transportation Institute (Ref. 6) and from some survivor curves from an older Planning Survey Study (Ref. 7) in Texas.

It was necessary to devise a method for adjusting the pavement life when either an increase in truck volume or heavier trucks are operated over a road segment. This adjustment procedure was based on the results of a study conducted by the American Association of State Highway Officials (AASHO). That study (Ref. 8) included a large scale road test that had as one of its objectives:

> *to determine the significant relationships between the number of repetitions of specified axle loads of different magnitudes and arrangement and the performance of different...* pavements. (Emphasis and paraphrasing added for simplification.)

This experiment cost about 30 million dollars and is considered the most definitive work ever performed to obtain the relative effect of different sized trucks on pavements. The methodology of the AASHO Road Test provides the capability of converting any size axle load to a standard load (18,000-pound single axle) in terms of the damage to pavements (Ref. 9). The expected pavement lives, i.e., the survivor curves, were shortened in proportion to the increase in equivalent axle loads supplied from the projected traffic discussed in Chapter II.

It was also necessary to institute this additional aging of the pavements at the expected time of occurrence of the heavier trucks. To illustrate this concept, suppose the total expected life of a particular pavement in Scenario A is ten years and it has four years of remaining life. Further, suppose that the heavier trucks of Scenario B would double the rate of damage to the pavements based on the equivalent load concept mentioned above. With the change in truck loading, the remaining life of the road would then be only two years.

Another revision to REHAB was necessary. Following the accelerated wearout of the existing pavements, it would be desirable to re-design the pavement structures to properly handle the heavy trucks. The program was revised to accomplish this for that portion of the pavements receiving major rehabilitation. The original survivor curves (those developed under more recent weight standards with longer lives) were then applied to these pavements. The increased cost to accommodate heavier trucks was estimated to be proportional to the ratio of the logarithm of the heavy traffic equivalencies to the logarithm of the original traffic equivalencies. This methodology is also based on the findings of the AASHO Road Test (Ref. 9). Table 3-2 shows the relative magnitude of the changes made in the inputs.

In summary, the necessary revisions changed the REHAB program so that the following operations occur:

- When heavier trucks are applied, the life curves are shortened, causing a faster wear-out of the pavements.

- The "worn-out" pavements are rehabilitated. Those receiving minor rehabilitation (thin overlays) continue to wear out at the accelerated rate. However, those receiving major rehabilitation are redesigned at an increased cost to handle the heavier trucks. These redesigned pavement structures now begin to wear out at a slower rate. The slower rate is the same rate as the original life curves for these pavements.

BASIS FOR BRIDGE COST ESTIMATES

The Federal Highway Administration and AASHTO have developed a formula for calculating a Sufficiency Rating for bridges. This formula takes into consideration structural adequacy and safety features, serviceability and functional obsolescence, and essentiality for public use. If a bridge has a calculated Sufficiency Rating of less than 50, it can be considered eligible for replacement under the National Special Bridge Replacement Program.

Using the above formula and current bridge inspection data, a Sufficiency Rating was calculated for all bridges on the State highway system. The bridge replacement costs for Scenario A were developed by applying the same criteria that is used by the Federal Highway Administration in the National Special Bridge Replacement Program and adding additional load-restricted bridges.

Scenario B required evaluation of the effect of the increased truck loading on bridges. This was performed generally in accordance with the methodology given in Appendix B of NCHRP Report 141 (Ref. 3).

TABLE 3-2 COMPARISON OF REHAB INPUTS

	18,000# Equivalent Axle Loads Per 20 Years		Ratio of Pavement Life* in Scenario B to Scenario A	Ratio of Rehabilitation Costs in Scenario B to Scenario A
	Scenario A	Scenario B		
Interstate Highways				
Flexible Pavement	7,813,000	11,720,000	.667	1.026
Rigid Pavement	12,980,000	20,250,000	.641	1.027
Farm-to-Market Roads				
Flexible Pavement	92,800	194,800	.476	1.065
Rigid Pavement	141,100	278,800	.506	1.057
Other State Highways				
Flexible Pavement	871,700	1,602,000	.544	1.044
Rigid Pavement	1,308,000	2,435,000	.537	1.044

* Pavement Life before reconstruction to accommodate heavier trucks. After reconstruction the ratio equals one.

From computer listings representing all of the bridges on the Texas highway system, five types of simple span superstructures and seven types of continuous span superstructures were selected as representative of the entire system of bridges. Average span lengths were also assigned to these twelve types. Continuous spans were represented by an equivalent simple span length. The usual ratio of dead load moment to live load moment was established for each type by calculation and estimate. These vary slightly from those reported in the NCHRP Report 141 to more nearly correspond to Texas conditions. Each structure-type-span was considered for four design loadings (H10, H15, H20, and HS20) on each of three highway systems (Interstate, FM, and All Others). Live load moments due to one design truck or lane were taken from the AASHTO Bridge Specification, Appendix A, for each span. Moments due to one truck from the proposed legal loading, Scenario B, were calculated for each span using a computer program called BMCOL 43 (Ref. 10). Trucks represented by Scenario B were considered, and the absolute maximum moment for the span was used. The ratio of the Scenario B moment to the design load moment represents the increase in live load moment for each type-span. To convert this to stresses, the dead to live load ratio was used, and for prestressed beam bridges only, a factor evaluating composite action was included. The formula selected for calculating overstress is that used in Reference 3.

In order to evaluate the effects of the overstress, it was necessary to establish allowable values for the various types of bridges. For structural steel bridges, the steel stress was limited to 75 percent of the yield stress with capacity reduction factors in accordance with the maximum stress permitted by the AASHTO *Manual for Maintenance Inspection of Bridges* for operating rating. For these steel bridges, an overstress of 23 percent was considered allowable. For concrete bridges, an overstress of 26 percent was considered allowable.

Whenever the calculated overstress exceeded the allowable overstress, all bridges represented by the type-span-loading were considered inadequate for Scenario B loads and therefore required replacement. Where the overstress was less than the allowable, the bridges were considered adequate.

The number of bridges and their deck area were tabulated for each type-span-loading system. The deck area of bridges which are presently load restricted was tabulated and subtracted from the total to provide the bridge deck area that would be affected by the proposed changes for Scenario B. If the category showed excessive overstress, the cost of replacement was calculated by multiplying the affected deck area by the estimated unit cost of construction. Culverts were not considered to be affected because the maximum Scenario B wheel loads are less than the present design wheel loads. The bridge costs calculated are shown in Table 3-1.

[This page replaces an intentionally blank page in the original document. --CTR Library digitization project]

CHAPTER IV

DECREASED TRUCK OPERATING COSTS AND OTHER BENEFIT CONSIDERATIONS

A change in the truck weight limits will produce changes in a variety of costs and benefits associated with the movement of highway freight. Estimates of some of these changes have been made and are discussed in this chapter. In summary, the major quantifiable effects that can be expected under the higher weight limits of Scenario B are:

- $9.12 billion savings in truck operating costs;
- 2.42 billion gallons of fuel saved; and
- negligible changes in noise and air pollution in the urban area.

DECREASED TRUCK OPERATING COSTS

The primary benefit obtained by the hypothesized change in the weight limit accrues in the form of reduced operating costs in the trucking industry. The projected savings are shown in graphic form in Figure 4-1.

The projected $9.12 billion savings that occurs within the 20-year analysis period (1977-1997) was calculated using a procedure similar to one presented in the NCHRP Report No. 141. The data base for the operating costs was obtained by updating the cents-per-ton-mile numbers described in Appendix A of NCHRP-141 (Ref. 3).

The components of the total operating per-ton-mile costs are:

- repair, servicing, and lubricating costs;
- tires/tubes costs;
- fuel costs;
- driver wages/subsistence costs;

- overhead and indirect costs; and
- depreciation and interest costs.

Several different cost indexes were obtained and applied to the NCHRP data to update the operating cost information from 1970 to current 1977 levels in an attempt to derive a comprehensive measure of the resulting dollar savings. The resulting data collected from both public and private sources did not produce a set of compatible indexes for each of the six cost components. The general Consumer Price Index (CPI) was finally selected as the mechanism for updating the 1970 truck operating costs. Recently, published results of a study conducted by the Hertz Corporation suggest that increases in truck operating costs since 1975 were larger than those reflected in the CPI. The Hertz data, however, were not incorporated in the present analysis due primarily to time constraints. The savings shown in Figure 4-1 are probably on the low side due to the relatively more rapid increase in fuel costs not reflected in the estimates.

The projected ton-miles data (described in Chapter II) were allocated to the three highway systems; and within each of the three highway systems, the ton-mileages were further allocated to the selected vehicle types. As a result, the number of ton-miles being hauled by each vehicle weight class was calculated for each scenario. *The hypothesized change in truck weight limits allowed the heavier weight class vehicles to haul more of the ton-miles, which resulted in fewer trips and therefore lower aggregated costs of truck operations in Scenario B.*

On a disaggregated basis, the cost savings by types of systems are also presented in Figure 4-1. The main point to be concluded is that 50 percent of the calculated savings occur in the IH system, 42 percent on Other State Highways, and only 8 percent on the FM Road network.

FUEL SAVINGS

Due to the current interest in the energy situation, a separate analysis was conducted to examine what, if any, fuel savings might result from an increase in truck weights. From a review of the literature (Refs. 11 through 15) the following model was selected to relate gallons of fuel per mile (gpm) and gross vehicle weight (GVW):

$$\text{gpm} = .139 + .00145\ \text{GVW}$$

Using the above equation, intercity ton-mile fuel consumption rates were calculated. Projected fuel savings are shown in Figure 4-2. The fuel saved would be about 1.8 percent

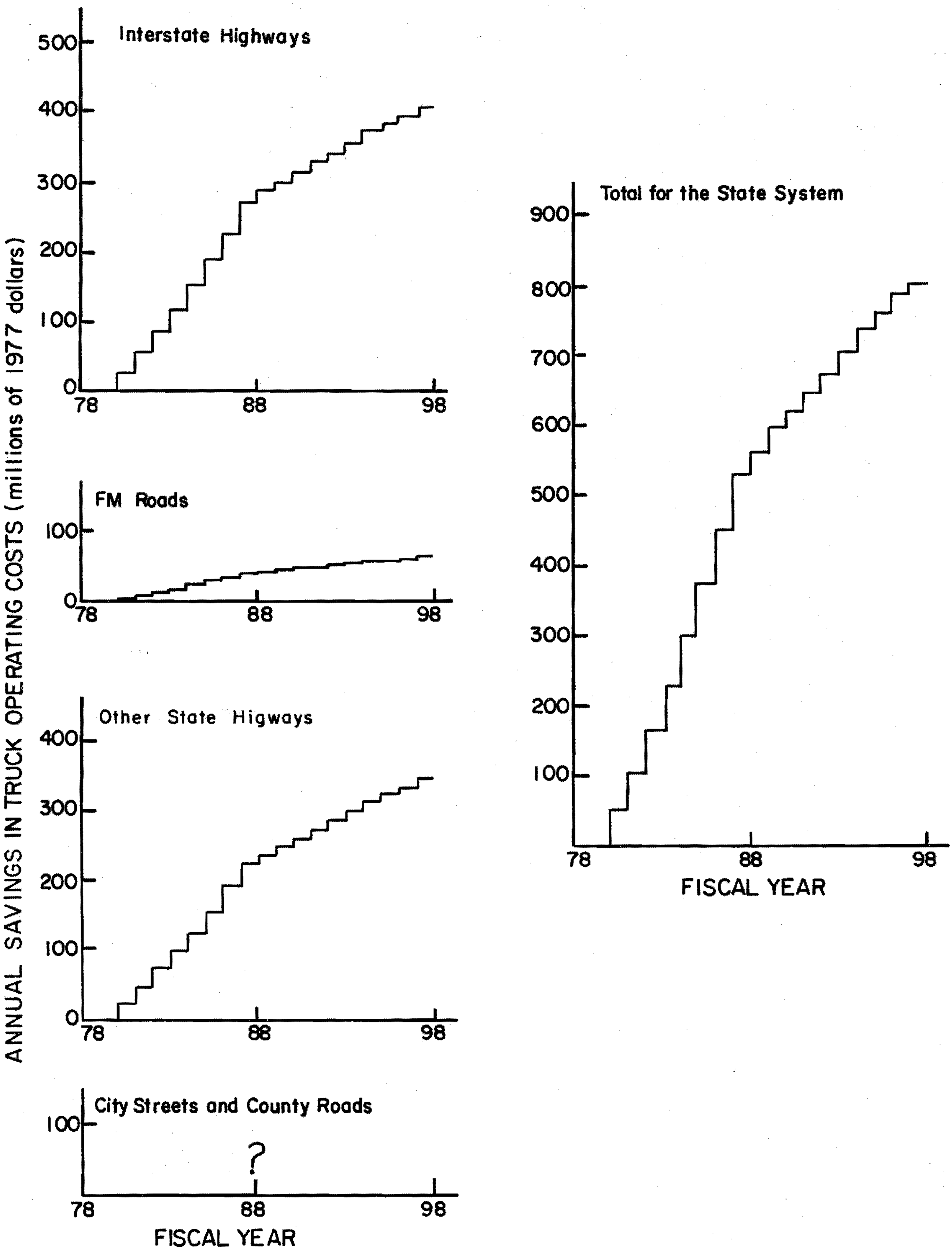


Figure 4-1. TRUCK OPERATING COST SAVINGS 1978-1997
SCENARIO B OVER SCENARIO A

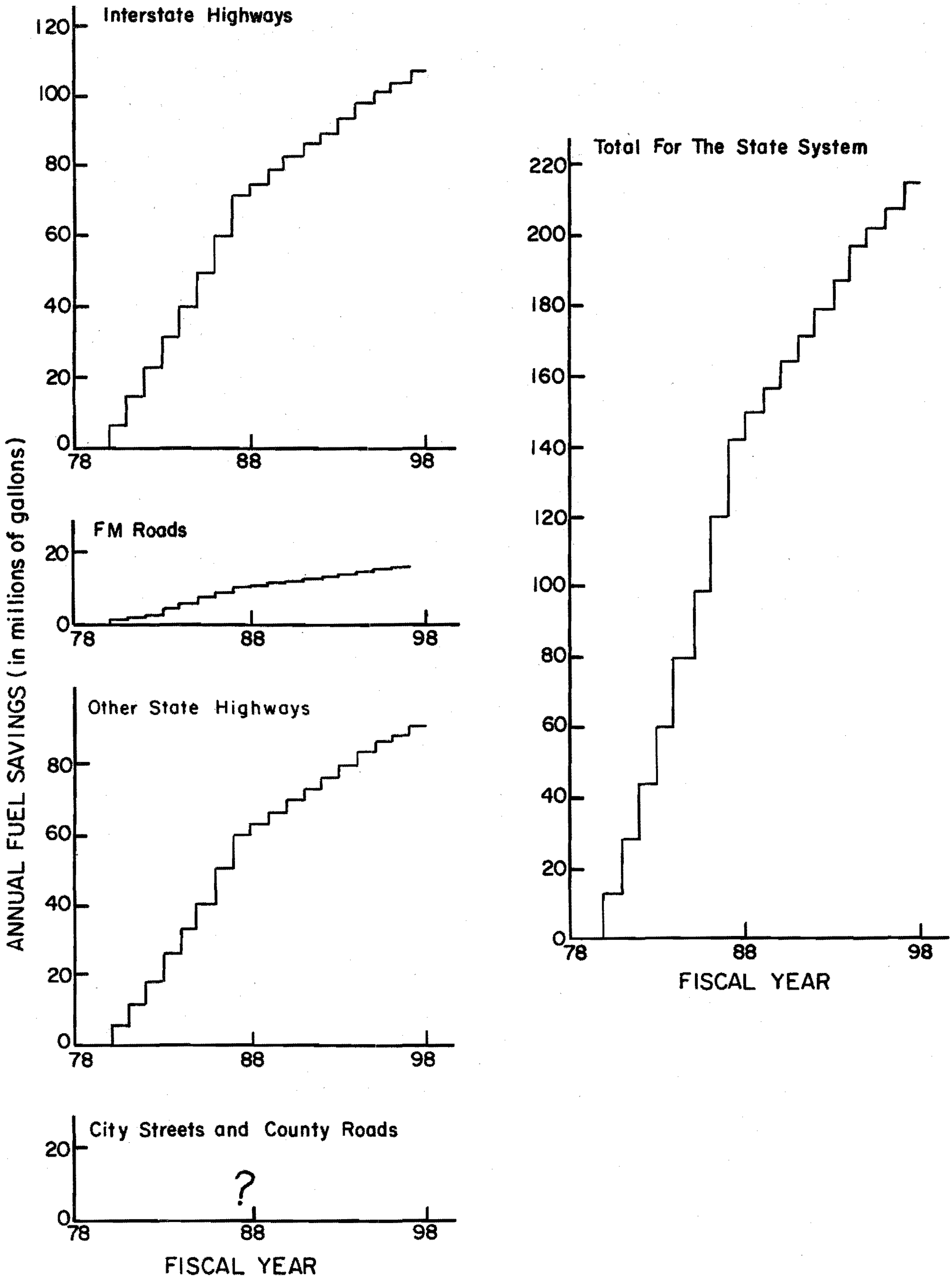


Figure 4-2 SAVINGS IN FUEL CONSUMPTION, 1978-1997
SCENARIO B OVER SCENARIO A

of the amount needed without the increase in truck weights. It should be emphasized that no additional increase in the total amount of freight movements were considered as result of the increase in truck weights. The total 20-year savings - - 2.42 billion gallons - - represents an amount approximately equal to 28 percent of all the motor fuel used in Texas in 1975.

AIR AND NOISE POLLUTION EFFECTS

Some analyses were completed in an attempt to relate vehicular pollution and changes in vehicle weights. The results are derived from previously developed models (Refs. 16, 17, 18). In the three major Texas metropolitan areas (Dallas-Fort Worth, Houston-Galveston, and San Antonio), a 3 percent to 6 percent reduction in air pollution caused by heavy trucks was calculated. Since heavy trucks contribute relatively small amounts to the total pollution emitted by all transportation, this calculated decrease represents a less than 1 percent reduction in transportation generated pollution.

The available data and research on noise pollution indicated that the hypothesized increase in axle weight limits should generate only small increases in noise along highways. Estimates of these reductions were not calculated because of the incompleteness of techniques in the state-of-the-art (Refs. 19 through 27).

[This page replaces an intentionally blank page in the original document. --CTR Library digitization project]

REFERENCES

1. Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights, Vol. 1 and 2, R. Winfrey and others, Federal Highway Administration, 1968.

2. Texas Regulations Governing the Size and Weight of Commercial Vehicles, Texas Department of Public Safety, 1975.

3. "Changes in Vehicle Weights and Dimensions," Robert E. Whiteside, et al., NCHRP Report No. 141, Washington, D. C., 1973.

4. Truck Weight and Vehicle Classification Study, Planning Survey Division, Texas Highway Department, 1960 through 1971, 1973 to 1975 from Federal Highway Administration.

5. Guide to the Highway Rehabilitation Forecasting Model, McKinsey and Company, 1976.

6. Research Project 2-8-75-207, "Flexible Pavement Evaluation and Rehabilitation," Texas Transportation Institute, unpublished data.

7. Road Life Study, unpublished, Planning Survey Division, Texas Highway Department, 1973.

8. The AASHO Road Test, Report No. 1, Highway Research Board Special Report 61A, 1962.

9. The AASHO Road Test, Report No. 5, Highway Research Board Special Report 61E, 1962.

10. "A Computer Program to Analyze Beam-Columns Under Movable Loads," Matlock, H., Taylor, Thomas, CFHR, Report 56-4, 1968.

11. "Financing Modern Highways for Montana," William L. Hall, a report on highway finances to the Montana Fact Finding Committee on Highways, Streets, and Bridges, Helena, 1956.

12. "Fuel and Time Consumption Rates for Trucks in Freight Service," Malcolm F. Kent, Highway Research Board Bulletin 276, Washington, D. C., 1960.

13. "Line-Haul Trucking Cost in Relation to Vehicle Gross Weights," Highway Research Board Bulletin 301, Washington, D. C., 1961.

14. "Supplementary Report of the Highway Cost Allocation Study," 89th Congress, 1st Session, House Document 124, Washington, D. C., 1965.

15. Truck Noise III - g, "Field Test of Freightliner Guided Truck," Erich K. Bender and Michael C. Kaye, prepared by Bolt Beranek and Newman, Inc., for the Dept. of Transportation, Washington, D. C., September 1975.

16. Ingalls, M. W. and K. J. Springer, Mass Emissions from Ten Pre-Controlled Gasoline Trucks and Comparisons Between Different Trucks on a Road Course. Southwest Research Institute, San Antonio, Texas, April 1975, prepared for U. S. Environmental Protection Agency.

17. Ingalls, M. W. and K. J. Springer, Mass Emissions from Diesel Trucks Operated Over a Road Course, Southwest Research Institute, San Antonio, Texas, August, 1974, prepared for the U. S. Environmental Protection Agency.

18. 1972 National Emissions Report, National Emissions Data System of the Aerometric and Emissions Reporting System, U. S. Environmental Protection Agency, June 1974.

19. Road Research Laboratory, "A Review of Road Traffic Noise." RRL Report, LR 357 (1970).

20. Staadt, Richard L., "Truck Noise Control," Reduction of Machinery Noise, Malcomb, J. Crocker (ed.), Revised Edition, 1975.

21. Motor Vehicle Noise Control, Special Report 152, Transportation Research Board, National Research Council, 1975.

22. Close, W. H., and Wesler, J. E., "Vehicle Noise Sources and Noise-Suppression Potential," Motor Vehicle Noise Control.

23. Priede, T., "Noise and Vibration Problems in Commercial Vehicles," Journal of Sound Vib., Vol. 5, No. 1 (1967) pp. 129-154.

24. "Transportation Noise and Its Control," U. S. Department of Transportation, June 1972.

25. Alan M. Voorhees & Associates, Inc., "An Analysis of the Economics of Truck Sizes and Weights in Relation to State and Federal Regulations," prepared for Motor Vehicle Manufacturers Associates, September 1973.

26. Agent, Kenneth R., and Rizenbergs, Rolands, L., "Vehicle Noise Survey in Kentucky," Highway Research Record, No. 580 (1976).

27. "Noise: New Federal/EPA Regulation Governing Interstate Motor Carriers," U. S. Environmental Protection Agency, April 1975.

28. Private conversations with Robley Winfrey.

29. Truck Traffic Volume and Weight Data for 1971 and Their Evaluation, Report FHWA-RD-76-138, December 1976, Final Report. R. Winfrey, P. D. Howell, P. M. Kent.

[This page replaces an intentionally blank page in the original document. --CTR Library digitization project]

APPENDIX

MODIFICATION
OF THE
NCHRP 141 METHODOLOGY

APPENDIX

MODIFICATION OF THE NCHRP 141 METHODOLOGY

Initial efforts in this study utilized the NCHRP 141 methodology with only those minor modifications necessitated by either absence of required data or a different form of available data. These minor deviations are described throughout the body of the report. Examination of the results being obtained and the basic assumption being used led the researchers to conclude that a part of the NCHRP 141 methodology is incorrect. This Appendix describes the NCHRP procedure, examines its fallacy, and reports the reviewed methodology adopted.

In order to predict what will happen to the distribution of gross vehicle weights for the various types of trucks after a law change, the NCHRP researchers examined measured GVW distributions before and after size and weight law changes. A pattern existing in this data shows a shift to heavier trucks with a small shift on the empty weight portion of the distribution. A shift approximately proportional to the ratio of the practical maximum gross weight under the new law to the practical maximum gross weight under the old law exists on the loaded weight portion of the distribution. Figure A-1 illustrates this trend. These historical shifts were modeled by a shift that started with no change for the smallest vehicle increasing proportionately to a shift equal to the ratio of practical maximum gross weights mentioned above.

The results of applying this type of shift to 100 vehicle miles of Scenario A of 3-S2 trucks is shown in Figure A-2. Figure A-2a shows a large decrease in 18 KSAL for trucks operating near the present legal limit. This decrease is negated by the increase caused by the new heavy trucks. Figure A-2b is similar except that a large savings in truck operating costs is indicated for empty and lightly loaded vehicles. *Such data caused the authors to re-examine the shifting procedure.*

One might expect the following to happen if weight (only) laws were changed:

- Those trucks operating near the legal axle or gross weight limit would increase their loads. This might or might not require a heavier vehicle. Fewer trips would be required to carry the same freight for this group of vehicles. Fewer empty or return trips would be required.

- Some vehicles carrying low density cargo are constrained by volume (size) of their vehicles. These trips would be unaffected on both the loaded and empty trips.

- A significant number of trips are made where the vehicle is only partially loaded. Some of these are delivery trips wherein the weight decreases or increases along the route. Segments of these trips may be affected by the law change, while the less loaded trips are made because the demand is only for a partial load. These trips will be unaffected by the law change.

It was concluded that a shifting procedure should be used that would have the following characteristics:

- Heavily loaded vehicle trips would shift to a larger GVW in proportion to the previously mentioned ratio of practical maximum gross weights.

- Lightly loaded vehicles would be unaffected by the law change.

- Empty vehicle trips would be reduced in proportion to the reduction of loaded vehicle trips.

It is postulated that the historical changes in GVW distributions used as a basis for the NCHRP shift were the result of factors other than weight law changes. It is possible that trucks were becoming heavier with time, and that concurrently with weight law increases, size increases were also permitted. This was discussed with one of the principal researchers involved with NCHRP 141 (Ref. 28). In general, he concurred with the concepts presented herein.

To explore this phenomenon, a sensitivity study was conducted examining the effects of several possible shifts on the computed savings in truck operating costs and increased 18 KSAL. In general, truck operating cost savings are more sensitive than 18 KSAL are to shifts that increase weights of lightly loaded trucks. Further, for shifts that affect primarily heavily loaded vehicles neither output is extremely sensitive to the shifting procedure.

The results obtained with the shifts are illustrated in Figures A-3 and A-4. Note that for the adopted shift (SDHPT shift) the following results were obtained.

- Fewer empty trips resulted in savings.

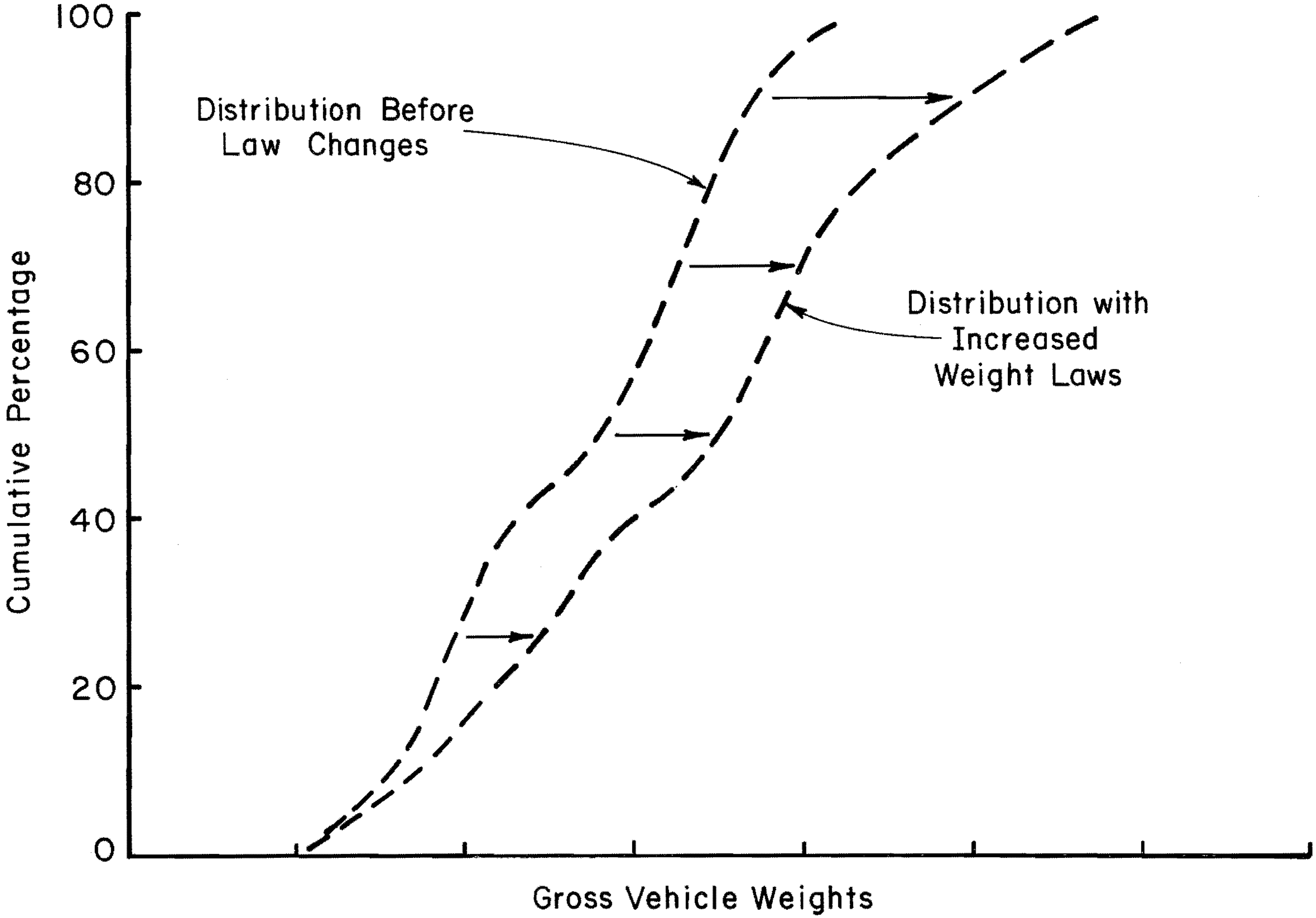
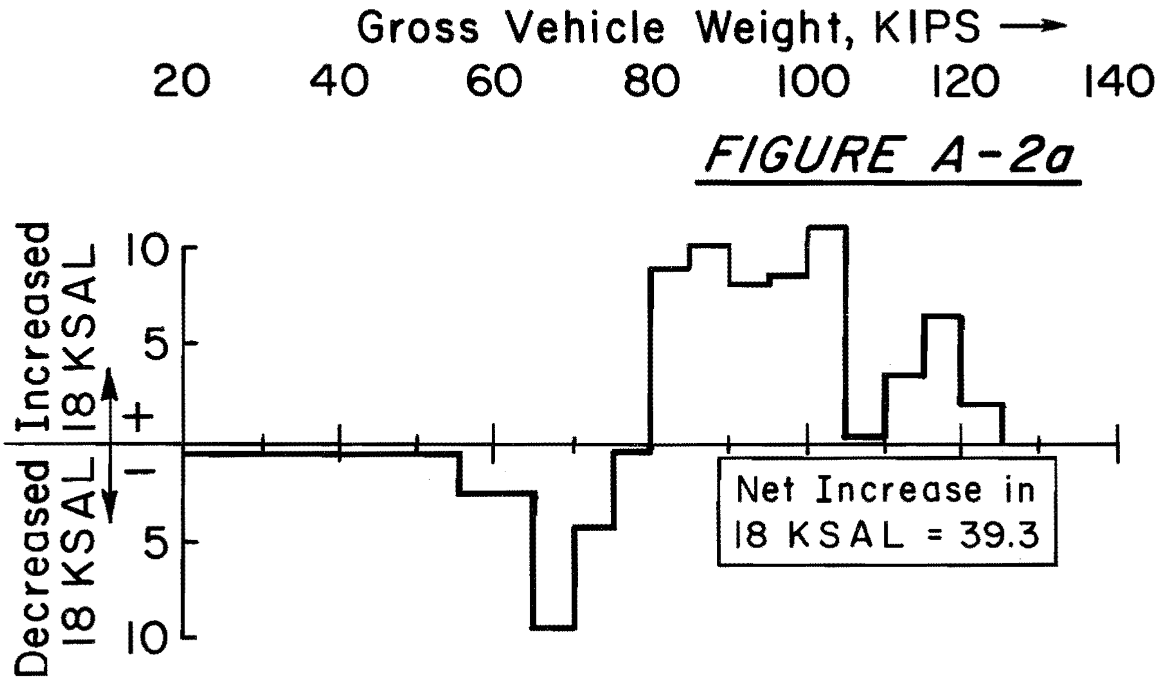


Figure A-1 Typical Historical Shifts In Gross Weight Distributions



100 3-S2 Trucks in Scenario A on a Representative One Mile of Interstate Highway, 61.7 Trucks with the Same Pay Load in Scenario B.

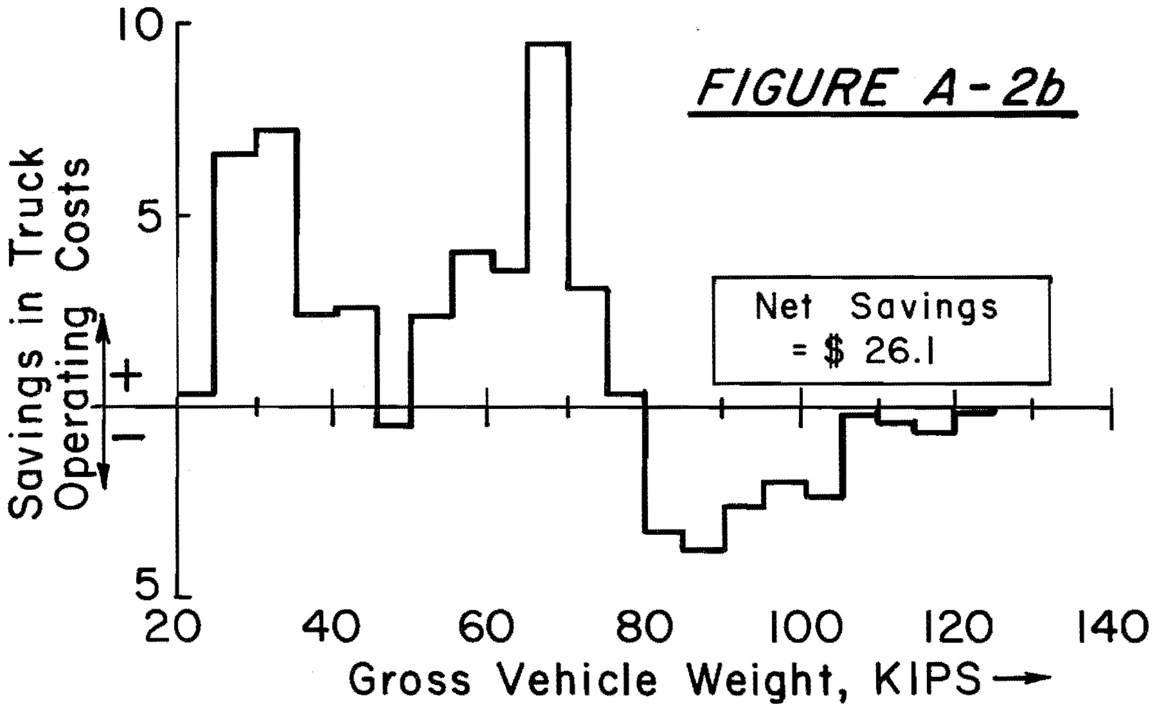
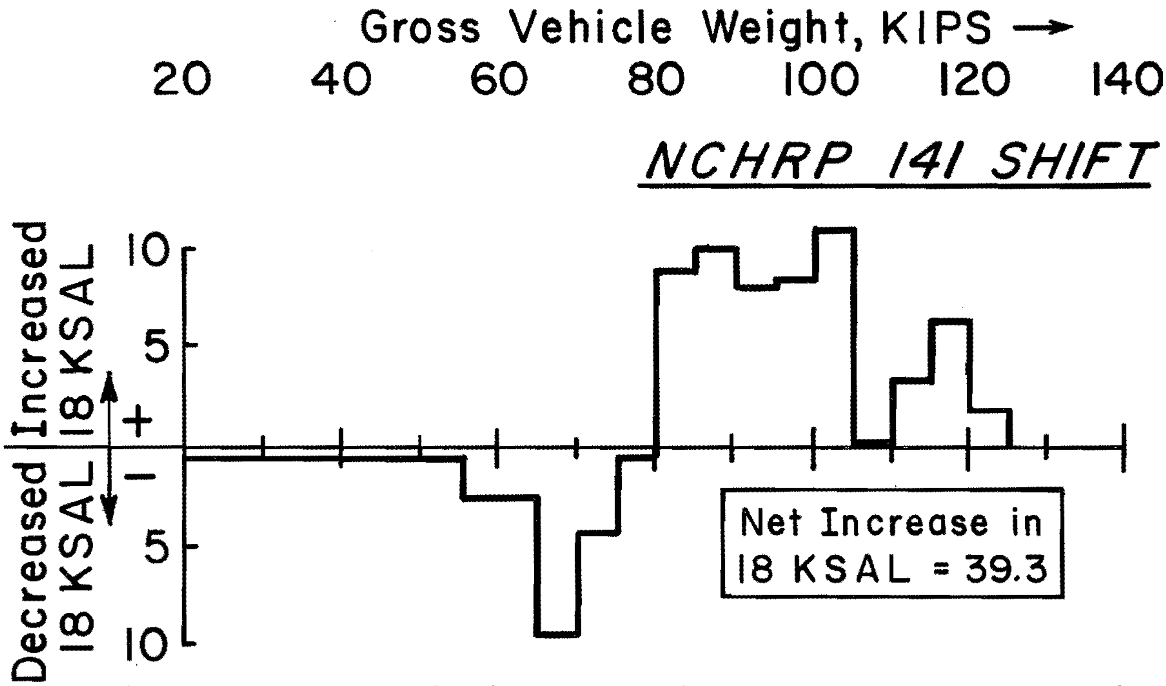
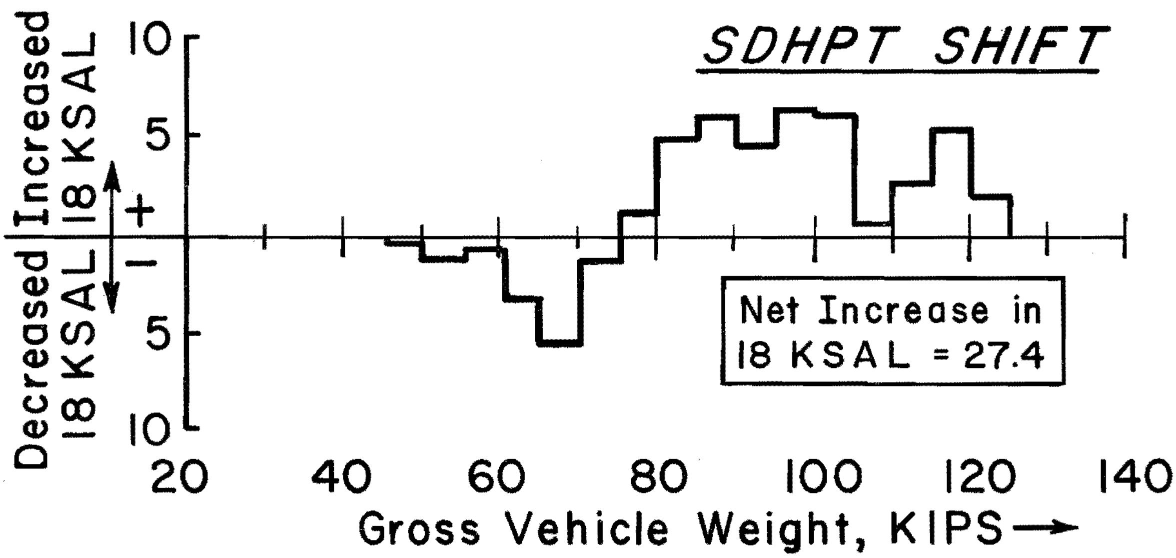


Figure A-2 Results Obtained With NCHRP Shift

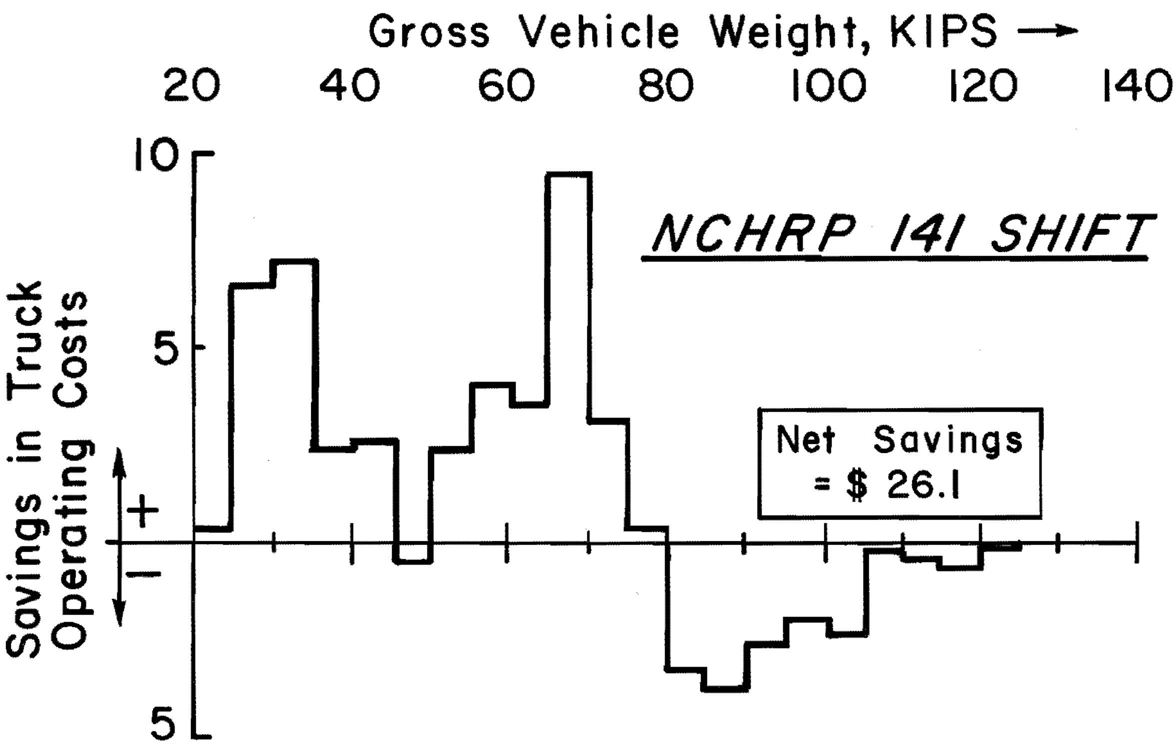


100 3-S2 Trucks in Scenario A on a Representative One Mile of Interstate Highway, 61.7 Trucks with the Same Pay Load in Scenario B.

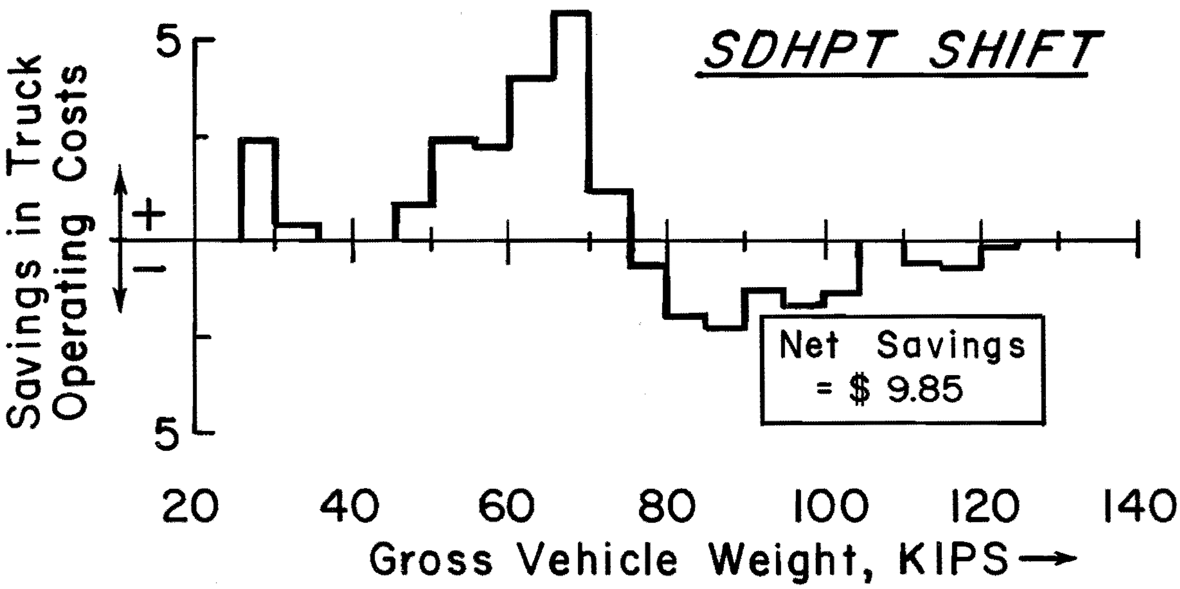


100 3-S2 Trucks in Scenario A on a Representative One Mile of Interstate Highway, 85.7 Trucks with the Same Pay Load in Scenario B.

Figure A-3 Change in 18 KSAL vs GVW



100 3-S2 Trucks in Scenario A on a Representative One Mile of Interstate Highway, 61.7 Trucks with the Same Pay Load in Scenario B.



100 3-S2 Trucks In Scenario A on a Representative One Mile of Interstate Highway, 85.7 Trucks with the Same Pay Load in Scenario B.

Fig. A-4 Change in Truck Operating Costs vs GVW

- Some partially loaded or lightly loaded trucks were unaffected.
- Trucks possibly constrained by axle or gross weights laws were reduced.
- Trucks exceeding the present law (but constrained by the future law) were increased. This resulted in increased savings.
- Net savings in truck operating costs were affected much more than net increase in 18 KSAL by the adopted shift versus the NCHRP 141 shift.

Figure A-5 shows the NCHRP and SDHPT shifting factors. The SDHPT shift is considered a "most likely" outcome; however, it must be pointed out that the basis for its selection lacks precision. The following quotation from the letter of transmittal for Reference 29 is given to show how uncertain present knowledge is on this subject.

> "Considering the fact that local gross weight limits have increased steadily during the past two decades, the major findings that there has not been a marked change in total truck traffic nor in average gross or axle weights during the period 1966 to 1972 are surprising. This result may be a reflection of trends in actual gross weights due to more haulage of manufactured goods or may be due to avoidance by truckers of fixed weighing station locations."

For much cargo, the point of diminishing returns as far as gross or axle weight limitations are concerned may have already been reached!

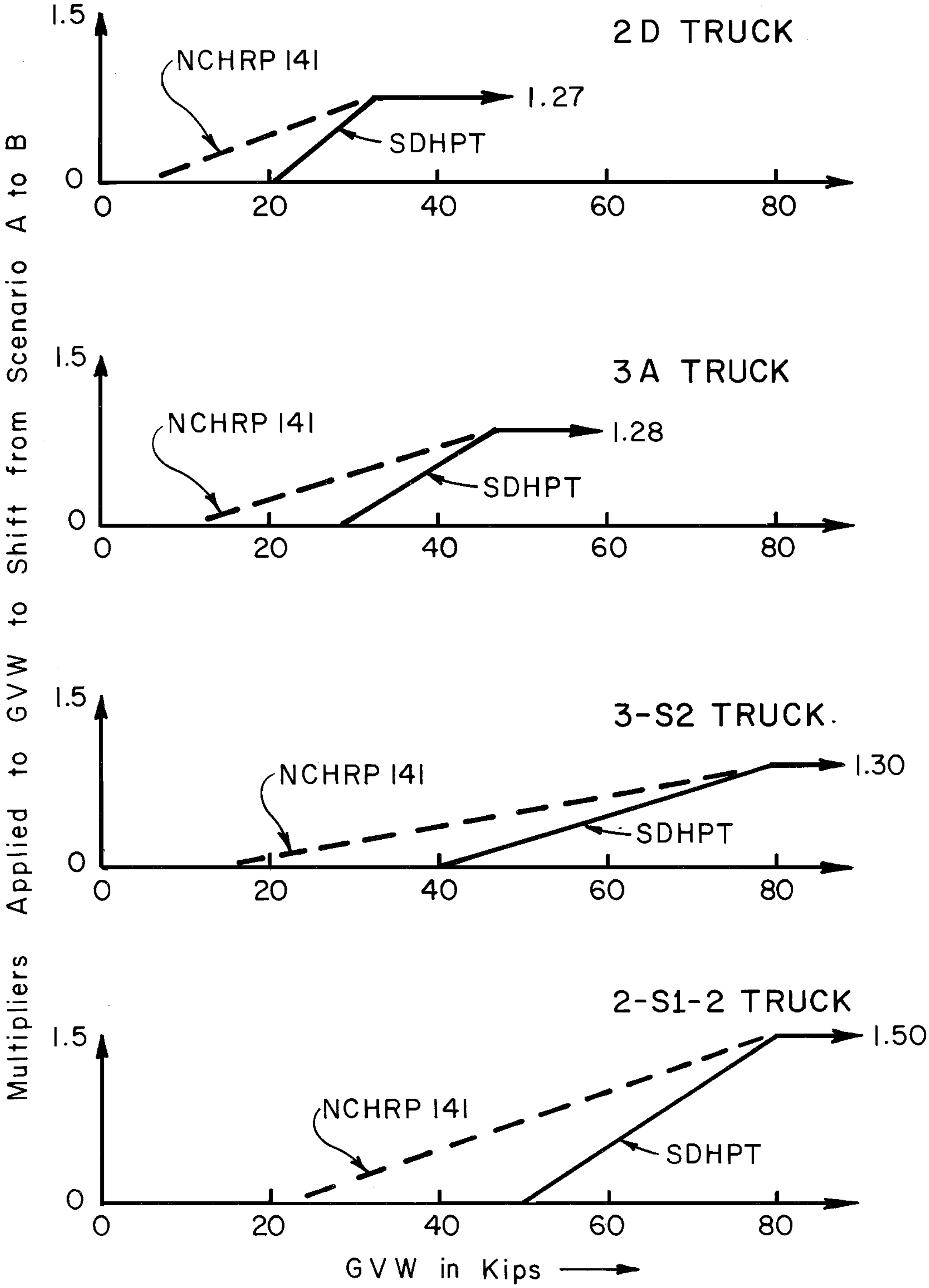


Figure A-5 Multipliers Adopted for Shifting GVW Distributions from Scenario A to B