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MICS OF THE MAXIMUM LIMITS OF MOTOR VEHICLE SIONS AND WEIGHTS

Vol. 2

R. Winfrey and others

September 1968
Final Report

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16. Abstract

Determining the desirable maximum limits of dimensions and weights of motor vehicles is approached on the basis of highway cost and the operating cost so far as the factors of economy are concerned. Axle weight, gross vehicle weight, and vehicle length are analyzed on the basis of six highway systems consisting of the rural and urban systems within the Interstate, primary and secondary highway systems. The analysis is based on data on truck weight studies conducted in 46 States; operating cost data obtained from truck fleet operators; and experimental data on pavements and bridges obtained from the comprehensive AASHO road test. Numerous other studies also contributed to the findings of the report.

The desirable limits of dimensions and weights were found to be the following:

1. Vehicle height of 13.5 feet
2. Vehicle width of 102 inches
3. Maximum lengths on all highways of 40 feet for single-unit trucks and trailers, 55 feet for tractors and semitrailers, and 65 feet for any other combination of vehicles.
4. Axle weight limits of 22,000 and 38,000 pounds for single and tandem axles respectively.
5. Gross weight limit of at least 120,000 pounds, or better yet, no gross weight limit at all with control of axle weight and spacing.

17. Key Words Sizes and weights; load limits; benefit-cost analysis; economy of truck transport; trucking cost; truck dimensions; truck axle weights; legal limits of vehicle dimension and weights; economic vehicle dimensions and weights; highways and truck limits	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C. 20590

May 1974

This report should provide useful perspectives to transportation agencies and legislative bodies responsible for recommending changes related to motor vehicle sizes and weights regulations and policies.

This report was originally produced in 1968 but was not released for publication until a thorough review of the findings and methodology was completed. This review, titled "Summary and Assessment of Sizes and Weights Report" (Report No. FHWA-RD-73-67) is a companion volume which is required reading for anyone who seriously considers using the findings reported in the subject report. The assessment extends the analysis, examines assumptions made by Winfrey and others, and points out particular limitations of the "Sizes and Weights" report.

This report demonstrates a substantial economic benefit to be obtained by rebuilding the highway system to higher weight limits and advocates an "immediate" implementation of policies to move in that direction. In addition, vehicles hauling heavier loads would need to be designed with adequate propulsion, braking, steering and suspension systems to operate safely and efficiently with mixed traffic on the upgraded highway system. However, any substantial increase in legal loads without a massive program to update, monitor, and maintain the highway system would create disastrous effects in many States. Many pavements would need to be overlaid and bridges reinforced or posted for limiting maximum loads. These consequences of an immediate increase in legal vehicle size and weight restrictions without an investment to upgrade the capacity of existing pavements and bridges were not analyzed.

Important related questions not addressed in this report:

1. Is it in the national interest to encourage further shift of cargo from other transportation modes to highways, even when more economical?

2. How are the conclusions affected by increased fuel costs and limited petroleum supplies?

Both of these questions have gained considerable importance in the years following the original preparation of the report and should be considered in evaluation of specific size and weight policies or proposed legislation.

Charles F. Scheffey
Director, Office of Research

PREFACE

This 1968 research report is the direct result of a project started in September 1963 as an outgrowth of the report completed by the Bureau of Public Roads in 1963, revised and resubmitted to the Department of Commerce in January 1964, and finally published in August 1964 as House Document 354, 88th Congress, 2d Session. The 1963 report on the desirable dimensions and weights of motor vehicles came into being as the fulfillment of Section 108(k) of the Federal-Aid Highway Act of 1956.

For many years prior to the beginning of the study of the limits of dimensions and weights of motor vehicles, as a result of the 1956 Highway Act, the Bureau of Public Roads and the American Association of State Highway Officials were active on the subject. The list of references in Appendix A of Volume 2 gives the more important papers appearing since 1920.

This 1968 report does not specifically review the literature on the subject. Further, the report does not discuss the state of the art, the good and bad aspects of prior work, opinions, and policies. Rather, the research project which resulted in this 1968 report was designed to accomplish the specific results herein reported.

Two quotations from House Document 354 (1964) will help to place this 1968 report in proper perspective. In the Letter of Transmittal the Secretary of Commerce says,

> The findings of the report do not necessarily represent the ultimate maximum limitations that would be desirable, or any improved methods of governing motor vehicle dimensions and weights. Such improved methods are under study as part of the comprehensive highway research program of the Department. A research plan to realize more modern approaches to size and weight administration is suggested in the report.

On page 2, under Summary and Recommendations, the report states,

> The resources of technical research available for this report have been considerable; nevertheless, the field is so complex and the variables so many that each conclusion is subject to important qualifications. Furthermore, the interrelationship between each conclusion requires further exploration to provide overall solutions for a highway system. The conclusions available from present research cannot justify greater standards than those proposed in this report; a more comprehensive program of research and investigation must proceed to enable future standards to be related specifically to technical criteria, and applicable to additional components of the Federal-aid highway systems.

One important factor missing in all prior reports (except the preliminary analysis in House Document 354) is any analyses to show the transportation economy of the limits of vehicle dimensions and weights. Prior studies stressed the design of pavements and structures and traffic safety. Thus, this report is the first to explore thoroughly the economy of the limits of vehicle dimensions and weights, considering both highway cost and motor vehicle transport cost.

About 1945 the Highway Research Board appointed a Committee on Economics of Motor Vehicle Size and Weight. This committee is still in existence, though less active than it was up to about 1962. The long tenure of the committee indicates that there was early and continued interest in the subject and that the objectives have not been achieved. The Highway Research Board committee was the motivating force which produced Highway Research Board Bulletin 9A on time and fuel consumption of trucks on grades and Bulletin 301 on the overall operating cost of line-haul trucks.

This present 1968 report has as its main objectives the development of the economic and technical guides essential to policy and legislative considerations and the procedural techniques for future research application. There is no attempt (at least not a deliberate one) to recommend what public policy should be or to recommend changes in the Federal and State laws. For this reason the AASHO policy on maximum dimensions and weights of motor vehicles as published October 21, 1963, is not discussed.

House Document 354 (1964) and this 1968 report furnish recently assembled facts for the guidance of policy makers on the probable consequences of increasing limits of vehicle dimensions and weights.

ACKNOWLEDGMENTS AND STAFF

This report on the research project to determine the desirable dimensions and weights of motor vehicles is the result of individual work by some 50 or so persons, including some 30 professionals working as a task force. To all these individuals, whether or not they are named here, full appreciation for their contribution is expressed.

The project as a whole was directed by Robley Winfrey, who is also responsible for the design and the writing of the overall report of the project and this condensed report. Certain sections of these reports, however, were extracted from separate staff reports.

Much of this report is supported by separate staff reports and research on the individual studies into which the main project was divided, studies that were assigned to specialized members of the task force. These staff reports and their authors are listed at the end of these acknowledgments.

Special credit is given to the late Hoy Stevens of the Traffic Systems Division, Office of Research and Development, for his overall counsel on many aspects of the research. Professor Robert G. Hennes of the University of Washington, Special Consultant, offered many suggestions and helpful discussions.

A special word of appreciation is also due Professor William G. Adkins of the Texas Transportation Institute, Texas A&M University, and Professor Hennes for their comprehensive review of the manuscript. The report benefited from their helpful suggestions.

Elizabeth Samson is especially mentioned for her painstaking efforts in editing manuscript, arranging for the production of all materials, and for supervising the work of the assembly of the report. Her splendid performance freed the project leader to concentrate on analysis of the results and writing of manuscript. Miss Samson also reviewed the State laws and brought up to date the summary of maximum limits given in Chapter 3.

Malcolm F. Kent made important contributions in connection with adopting the procedure of calculating equivalent 18,000-pound axle weights for the computer program, the analysis of hauling 2,000 tons of payload by different classes of vehicles, and in summarizing the A. T. Kearney report and reducing its results to pavement costs.

Charles Dale contributed to the 2,000-ton study following Mr. Kent's retirement. Duke Niebur computed the truck operating costs to accompany the Kearney-Kent study, as well as refining the early calculations by Mr. Kent and Mr. Dale. Mr. Niebur also did the work on the marginal limits of axle weight, gross vehicle weight, and average daily traffic. He also developed the relationships between empty vehicle weight, horsepower, and practical maximum gross vehicle weight.

James R. Link wrote the computer program for the pavement design, motor vehicle operating costs, and the early phases of the computer program for the financial cost of reconstruction and resurfacing. Ezio C. Cerrelli wrote the computer program for calculating the E 18-kip axles for each type of vehicle and completed and perfected the program for the financial studies.

Maude M. Sparagna, William F. Warlick, Lillian Washington, Carol B. French, Barbara A. Price, and Edna Wolf performed hundreds of thousands of general statistical calculations, coding entries, and transfers of data involved in the economy and financial studies.

Typing of the report was done largely by Agnes McHugh, Carol B. French, Marian Higgins, and Linda Cameron, though many other typists, stenographers, and secretaries in the Economics and Requirements Division and elsewhere contributed greatly to this major task.

Special acknowledgment is due the Office of Planning for cooperation and assistance in making available the truck weight study data. Appreciation is expressed specifically to Alexander French, Ted Dickerson, and Alma Clark. The Office of Engineering and Operations and the Office of Administration furnished many construction statistics by highway systems that were important factors in the study.

The project leader gratefully acknowledges the support and teamwork of the professional and support members of his Engineering Economy Group, which shouldered the responsibility for Chapters 4, 7, 8, and 10 through 17. The study leaders are especially thanked for their cooperation and fine production in the accomplishment of the objectives of the study as a whole.

STAFF REPORTS AND AUTHORS OF INDIVIDUAL STUDIES OF THE OVERALL PROJECT

Study No.	Title of Staff Report	Authors
1	A Forecast of Highway Traffic by Vehicle Type, 1962-1990	Edmond L. Kanwit Walter H. Bottiny Alma F. Eckartt Beatrice T. Goley
2	Analysis of the Truck Weight Frequencies and ADT Composition by Road Systems (Results not written up as a separate staff report, but incorporated directly into the overall project report.)	Principal investigators were R. W. L. Doering Phebe D. Howell
3	Urban Street System Use by Heavy Trucks	This study was not undertaken.
4	A Study of the Effect on Truck Transport Practice of Liberalizing Weight and Dimensional Limitations of Vehicles	A. T. Kearney & Company under research contract
5A	Braking Performance of Motor Vehicles as Found Operating on Public Highways	Samuel C. Tignor F. William Petring
5B	Offtracking of Vehicles on Turns	Hoy Stevens
5C	Relationship between Gross Weights and Horsepowers of Commercial Vehicles operating on Public Highways	John M. Wright
5D	Analysis of Accident Experience--Frequency and Cost of Accidents	Charles M. Billingsley
6	Pavement Design	H. D. Cashell Stuart Williams G. W. Ring, III T. J. Pasko
7	Highway Geometric Design	A. A. Carter J. W. Hess

Study No.	Title of Staff Report	Authors
8	Design of Structures	E. G. Wiles R. F. Varney C. F. Galambos
8A	Inventory of Bridges	Charles W. Dale Earle Newman
9	Highway and Structure Construction Costs (Results not written up as a separate staff report, but incorporated directly in the overall project report.)	Principal investigator was John G. Trapnell
10	Line-Haul Trucking Costs in Relation to Vehicle Gross Weights	Hoy Stevens
11	Analysis of the Economy of Motor Vehicle Size and Weight	Robley Winfrey R. W. L. Doering Phebe D. Howell
12	Financing	T. R. Todd James V. Boos
13	Effects of Increased Size and Weight Limitations on Other Modes of Intercity Freight Transport	E. M. Nolan
14	Regulation of Transport Carriers and Tariffs	Josephine Ayre
15	Public Attitudes Toward Increased Size and Weight of Vehicles	This study was not undertaken.

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DEFINITIONS

Vehicle - An assembly of wheels and axles with connecting frame and with or without a body for containing goods or people, which may be towed or moved under its own power over the highway. A passenger car, a bus, a truck, a trailer, a tractor are separate individual vehicles. Also, the word vehicle as used generally includes any combination of two or more separate vehicles such as a tractor and semi-trailer or a truck and full trailer.

Vehicle Combination - Two or more vehicles combined so as to move over the highway as one train of connected vehicles.

Unit - A single vehicle; one of the vehicles within a vehicle combination.

Truck or motor truck - A single self-propelled commercial motor vehicle carrying its load on its own wheels and primarily designed for the transportation of property or commodities. When used as a general term, "truck" may refer to any type of commercial motor freight vehicle or combination of vehicles.

Single-unit motor truck - A self-propelled motor truck constructed to carry only its own cargo and not equipped to pull a trailer.

Power unit or power vehicle - A general term referring to any vehicle equipped with an engine for propulsion and arranged to pull a trailer.

Tractor - A self-propelled motor vehicle designed primarily for pulling semitrailers and constructed so as to carry part of the weight and load of a semitrailer. (A tractor is basically a motor truck with a short wheelbase and no cargo body.)

Tractive truck - A motor truck constructed to carry a cargo body and to pull a trailer. (A trailer pulled may be either a semitrailer or a full trailer depending on whether the tractive truck is equipped with a semitrailer fifth wheel or a full trailer pintle hook.)

Trailer - A commercial motor vehicle designed to carry cargo and to be pulled by a tractive truck or a tractor. When used as a general term it may mean either a semitrailer, a full trailer, or a pole trailer, and may be equipped with any one of the various types of cargo bodies. (Trailers built as mobile living quarters are known as trailer coaches and mobile homes, but frequently are called house trailers.)

Semitrailer - A trailer equipped with one or more axles and constructed so that a substantial part of its weight and load is carried by the tractor or tractive truck which pulls the semitrailer. A semitrailer may have one or more load-carrying axles located under the rear half of the vehicle.

A semitrailer with two axles grouped under the rear half of the vehicle frequently is known as a tandem-axle semitrailer.

Full trailer - A trailer constructed so that its weight and load rests on its own wheels. It may have two or more load-carrying axles.

Trailer converter dolly - A short chassis assembly consisting of axle and wheel assembly, tires, springs, frame for lower fifth wheel, drawbar, and other parts designed to slip under the front end of a semitrailer to convert it to a full trailer.

Trailer combination or combination - A general term used to describe two or more vehicles, one of which is a power vehicle, that are connected together for operation on the road. In general, the name of each combination indicates the types of vehicles that are connected together in the combination.

Double-trailer or tandem-trailer combination - A tractor, semitrailer, and full trailer. This combination frequently is called a "double bottom" because it has two cargo bodies.

Line-haul service - also called over-the-road service--A general term designating truck operations over intercity and rural highways. Such operations may include some minor auxiliary off-highway operations, especially where the payload is picked up from a loading area off the public highway.

Tandem axle - Axle groups having two or more axles spaced more than 40 inches apart and no more than 96 inches apart. More generally, tandem axles are two axles spaced about 48 inches apart.

Cargo, payload, and freight - The material contents, commodities, or goods in the truck body which are being hauled and upon which the freight tariff is paid in common or contract carriage.

Empty weight - The weight of the entire vehicle or vehicle combination with driver on the road without any cargo, or payload, but with any packing material, racks and tools usually hauled for convenience and not for revenue. Vehicles carrying empty drums, pallets, crates, and other cargo containers or leveling devices are classed as with load.

Tare weight - The weight of the entire vehicle or vehicle combination, exclusive of driver, passengers, packing material, cargo containers, cargo handling devices, and all objects not a fixed part of the vehicle.

ADT - The average daily traffic expressed in numbers of vehicles of all classes unless specifically stated differently. The daily average is for the year unless stated otherwise.

Benefit-cost ratio or B. C. ratio - An index of the relative economy of one alternative as compared to another, expressed as the quotient resulting from dividing the equivalent uniform annual benefit in dollars by the equivalent uniform annual cost in dollars required to obtain the benefit.

<u>E 18-kip axles</u> - The number of single axles weighing 18,000 pounds which would be equivalent to another number of axles weighing more or less than 18,000 pounds, as measured by their effect on the pavement structure. A kip is 1,000 pounds.

<u>Motor vehicle operating cost</u> - The total cost of operating the vehicle in road service, including costs of repairs and servicing, tires and tubes, fuel, driver, overhead, depreciation, and interest, but excluding terminal costs of handling cargo, and road-user taxes.

SUMMARY

Key Words: economy of truck transport; trucking cost; truck dimensions; truck axle weights; legal limits of vehicle dimensions and weights; economic vehicle dimensions and weights; highways and truck limits

Determining the desirable maximum limits of dimensions and weights of motor vehicles is approached on the basis of the highway cost and the operating cost of motor trucks, so far as the factors of economy are concerned. Vehicle operations on the highway are concerned with the factors of gross vehicle weight per net horsepower, braking distance, traffic accident frequency and severity, and highway capacity. The placement of the vehicle on the roadway so far as the highway geometrics are concerned is a factor considered. Earthwork, the pavement and shoulder structure, and individual structures are the three items of construction cost affected by any change in vehicle axle weight or gross weight. Other items of the total highway, such as right-of-way, engineering, and traffic facilities, are considered to be unaffected by the maximum legal limits of dimension and weight.

In the economy studies, axle weight, gross vehicle weight, and vehicle length are analyzed on the basis of six highway systems consisting of the rural and urban systems within the Interstate, primary and secondary highway systems. The work

is further divided by the ten census divisions, which approximates a grouping of the States having the same limitations of dimensions and weights, even though these limits vary considerably among all States.

The main basis of the analysis is the 1962 data on the truck weight studies conducted in 46 States. The axle weights, gross weights, frequency distribution by class of vehicle, number of empty vehicles, and the payload carried per vehicle are the main data utilized in these studies.

Considering all the factors involved in determining the desirable limits of maximum vehicle dimensions and weights, the following general conclusions were reached:

1. From the standpoint of economy of transportation, there are no major benefits to be gained by a vehicle height in excess of 13.5 feet, so that any higher limit than 13.5 feet does not need to be seriously investigated at this time.

2. A vehicle width of 102 inches as a maximum is desirable for the reasons that it would improve the loading facilities for certain modular-dimension products, and that it would provide additional desirable space at the rear axle for improvement of the differential and the braking system.

3. Existing highways will accommodate vehicle combination lengths up to 65 feet including two trailers. On

the Interstate system with full access control, combinations 100 feet long are feasible utilizing two 40-foot trailers.

4. There is considerable economy in overall transportation to be gained by axle-weight limits up to at least 26,000 pounds single and 44,000 pounds tandem. The benefit-cost ratio of such increases is significantly large--say, somewhere between 3.0 and 20.0--depending upon the highway system, the census division, and the character of the traffic involved.

5. Increasing the maximum length of vehicles up to 65 feet and permitting the combination of tractor, semitrailer, and full trailer results in a decrease in truck operating cost up to 30 percent, with no measurable increase in highway costs.

6. Gross vehicle weight for combination vehicles is economical up to 25,000 pounds.

7. During the 20-year period from 1965 to 1984, for the 22/38-kip designs, highway construction on the Interstate and Federal-aid primary systems would cost 0.5 to 1.9 percent more than the estimated totals under existing axle-weight limits. The above percentages amount to $95,537,000 and $348,370,000, respectively, for the 20-year period.

8. On all highways, the use of the 22/38-kip axle-weight limits would result in a truck operating cost decrease of $36 billion for the 20-year period, 1965 to 1984.

A FEW FINDINGS IN BRIEF

The desirable limits of dimensions and weights

were found to be the following:

1. A vehicle height of 13.5 feet

2. A vehicle width of 102 inches

3. Maximum lengths on all highways of 40 feet for single-unit trucks and trailers, 55 feet for tractor and semitrailer, and 65 feet for any other combination of vehicles

4. Axle-weight limits of 22/38 kips, single/tandem axles for universal use

5. A gross weight limit of at least 120,000 pounds, or better yet, no gross weight limit at all with control of axle weight and axle spacing.

CHAPTER 10

ECONOMY OF MAXIMUM AXLE-WEIGHT LIMITS

In determining the economy of axle-weight limits, two basic factors must be considered: (1) the cost of operating motor vehicles at various levels of maximum axle-weight limit and (2) the cost of constructing and maintaining the highways for the use of the vehicles operating at these levels of axle-weight limit. The key to the analysis governing both the motor vehicle running cost and the pavement design is the composition of the trucking fleet (traffic) by axle classification of the vehicles comprising it and the weight distribution of single and tandem vehicles.

1. CONCEPTUAL APPROACH

The economy of transportation as related to maximum legal limits of vehicle axle weights is dependent upon the following factors: (a) the limits, (b) the highway costs incurred, (c) transport requirements, and (d) the character and use of transport. For the purpose of this study of the economy of axle-weight limits, the basic data available consisted of the results of the truck weight studies by the several States, the AASHO guides for pavement design, and highway construction costs from Federal-aid project records.

The procedures involved a forecast of truck usage of the highways to 1985, a forecast of the distribution of axle weights by vehicle class, an estimate of the payload to be hauled, and choice of specific axle-weight limits to be studied. A critical factor involved in this procedure is the method of determining the axle-weight distribution under axle-weight limits higher than now exist.

2. BASIC PROCEDURES AND METHODS

In the general study of the economy of maximum axle-weight limits, the basic procedure used was to estimate the axle-weight distribution for the assumed traffic composition, to design the pavement for these conditions, and to calculate the resulting highway and motor vehicle costs. It should be noted that upgrading of existing construction is not included in the highway cost on the ground that, if there is general transport economy in constructing new highways for increased axle weights, logically there would be economy in upgrading the structural quality of existing highways.

A. Levels of Axle-Weight Limits To Be Considered

The selection of the levels of axle-weight limits to be used is the fundamental first step in the study of the economy of maximum axle-weight limits, by whatever method it is to be accomplished. As shown in Chapter 3, the laws of the several

States usually set forth maximum limits for the axle weights of motor vehicles and also for their gross weights.

For this analysis of the economy of axle-weight limits, 18,000/32,000 pounds were selected as the lower weight limits for single and tandem axles, respectively, on the basis that they were the lowest in effect. Axle weights of 26,000/44,000 pounds were selected as practical upper limits that are above those now existing, with the single exception of the 44,000-pound limit in Florida. Still higher limits were used in the special study to determine the upper axle-weight limits beyond which no further gains in transportation economy can be expected (Chapter 14).

The five levels of maximum axle-weight limits shown below cover the current legal levels and two levels above. These five

Single axle weight, pounds	Tandem axle weight, pounds
18,000	32,000
20,000	35,000
22,000	38,000
24,000	41,000
26,000	44,000

levels were used throughout this study of the economy of limits of vehicle dimensions and weights.

B. Highway Systems and Census Divisions

In order to provide a measure of any effects on the economy of axle-weight limits that could be due to geographical location, existing State laws, and regional trucking practices, the study was applied separately to six highway systems in each of the ten U. S. census divisions. The highway systems are the following:

	Code	System name
	1	Interstate, rural
	2	Interstate, urban
	3	Primary, rural
	4	Primary, urban
5	5	Federal-aid secondary, rural, State jurisdiction
	7	Federal-aid secondary, rural, local jurisdiction
6	6	Federal-aid secondary, urban, State jurisdiction
	8	Federal-aid secondary, urban, local jurisdiction

The ten census divisions and the States included in each are as follows:

No.	Abbreviation	Census division	States included
1	NE	New England	Connecticut, Maine Massachusetts, New Hampshire, Rhode Island and Vermont
2	MA	Middle Atlantic	New Jersey, New York, and Pennsylvania
3	SAN	South Atlantic (North)	Delaware, Maryland, Virginia, West Virginia, and District of Columbia

No.	Abbreviation	Census division	States included
4	SAS	South Atlantic (South)	Florida, Georgia, North Carolina, and South Carolina
5	ENC	East North Central	Illinois, Indiana, Michigan Ohio, and Wisconsin
6	WNC	West North Central	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota
7	ESC	East South Central	Alabama, Kentucky, Mississippi, and Tennessee
8	WSC	West South Central	Arkansas, Louisiana, Oklahoma, and Texas
9	M	Mountain	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming
10	P	Pacific	California, Oregon, and Washington

C. Vehicle Classes

Figure 10-1 shows by axle arrangement 18 classes of cargo-hauling vehicles and vehicle combinations representing the more common types found on the public highways. Other classes found in traffic classifications do not appear in significant numbers.

The following vehicle types were used throughout the analysis as those vehicles that would be affected by an increase in legal dimensions and/or weights:

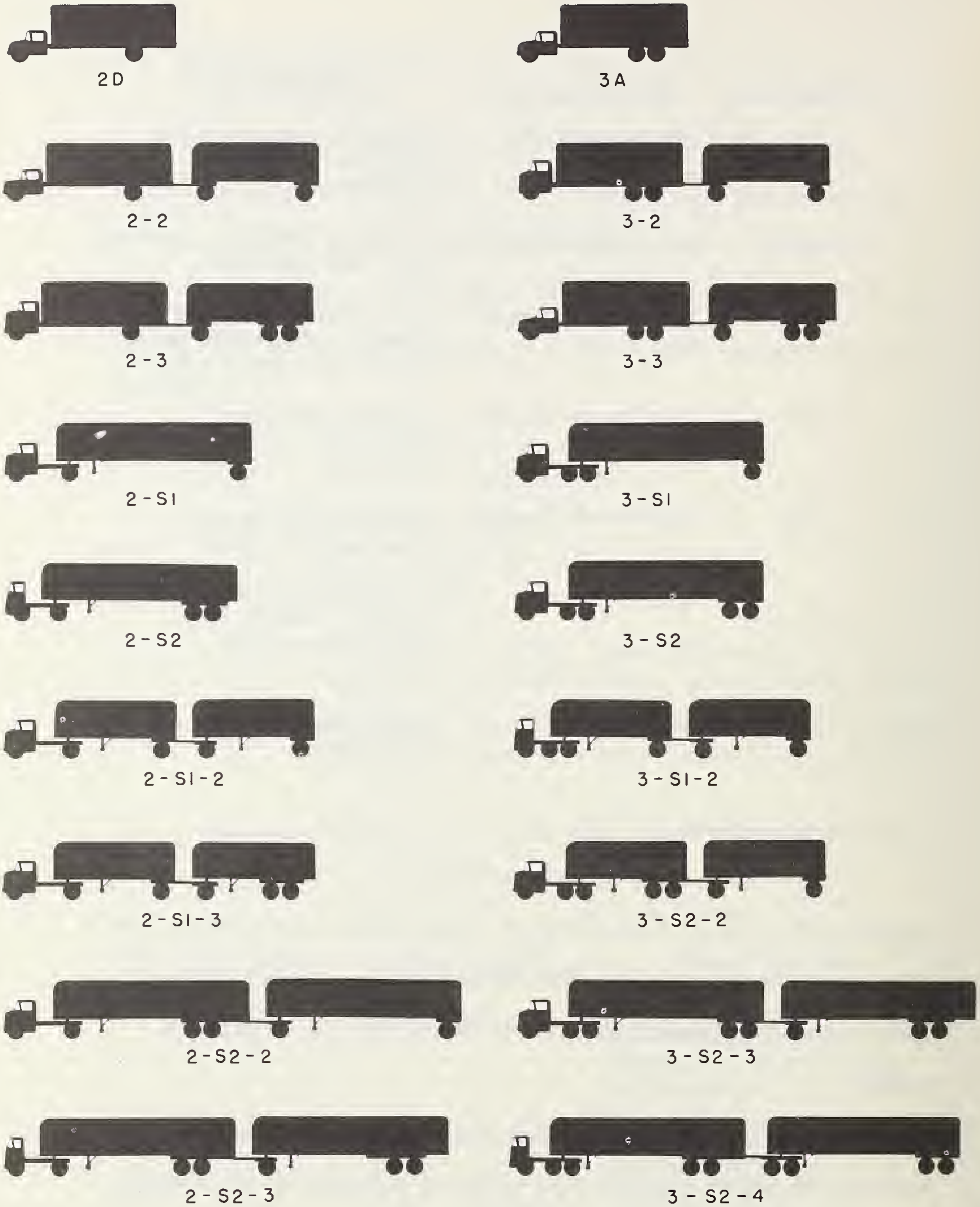


Figure 10-1. Axle arrangements and code designations for typical vehicles and vehicle combinations

Single-unit trucks	Tractor-semitrailers	Other combinations
2D	2-S1 (3 axles)	2-3, 3-2 (5-axle truck-trailers)
3A	2-S2 (4 axles)	2-S1-2 (5-axle tractor-semitrailer-full-trailer)
	3-S2 (5 axles)	

D. Adjustment for Increase in Average Payload Per Vehicle and for a Transition Period

Owing to the increase in average payload per vehicle in past years, an increase in typical payload per vehicle of 29 percent from 1962 to 1990 (28 years) was included in the forecast of traffic. The 29-percent figure was arrived at by studying the trends of truck weights and loading practices over the last several years.

In all of the analyses for the economy of increased dimensions or weights of vehicles, the total tonnage of payload to be transported was increased from the base tonnage in 1962 and forecasted to 1990 on the basis of a straight-line increase. The 1962 tonnage is that tonnage determined from the truck weight studies. The 1990 tonnage is based on the projected population and the share of total intercity freight to be carried by the motor vehicle. The period of analysis was the 20 years beginning January 1, 1965 and ending December 31, 1984.

The 29-percent payload increase per vehicle merely controlled the number of vehicles required to transport the total tonnage, fewer vehicles being required to haul a specific number of tons in 1990 than in 1962. In all of the analyses of the economy of axle-weight limits, the same number of payload tons was used at each axle-weight limit. Therefore, as the axle-weight limits were increased, fewer vehicle trips were required to transport the given number of tons of payload.

Because it is not reasonable to expect that the truck traffic would adjust to the higher limits overnight, if the laws should be changed to permit higher weights, a 5-year transition period from 1965 to 1969 was included. Figure 10-3 shows how this transition period was applied to each axle-weight limit.

To show the effect of the 29-percent increase in payload per vehicle and the transition period, complete studies were made with and without these two factors. Each factor noticeably reduces the indicated gain in economy with increased axle-weight limits. Because these two factors are logical and because they do affect the calculated economy, both of them were always included in subsequent calculations and, unless specifically stated, are included in all results given in this report.

3. METHOD OF ANALYSIS

Three basic methods were used in determining the distribution of axle weights and the number of equivalent 18,000-pound axle applications to the pavement under each of the five levels of axle-weight limits. Method 1 transferred the axle-weight distribution found in the 1962 truck weight studies in those States having the 20,000- and 24,000-pound axle limits to

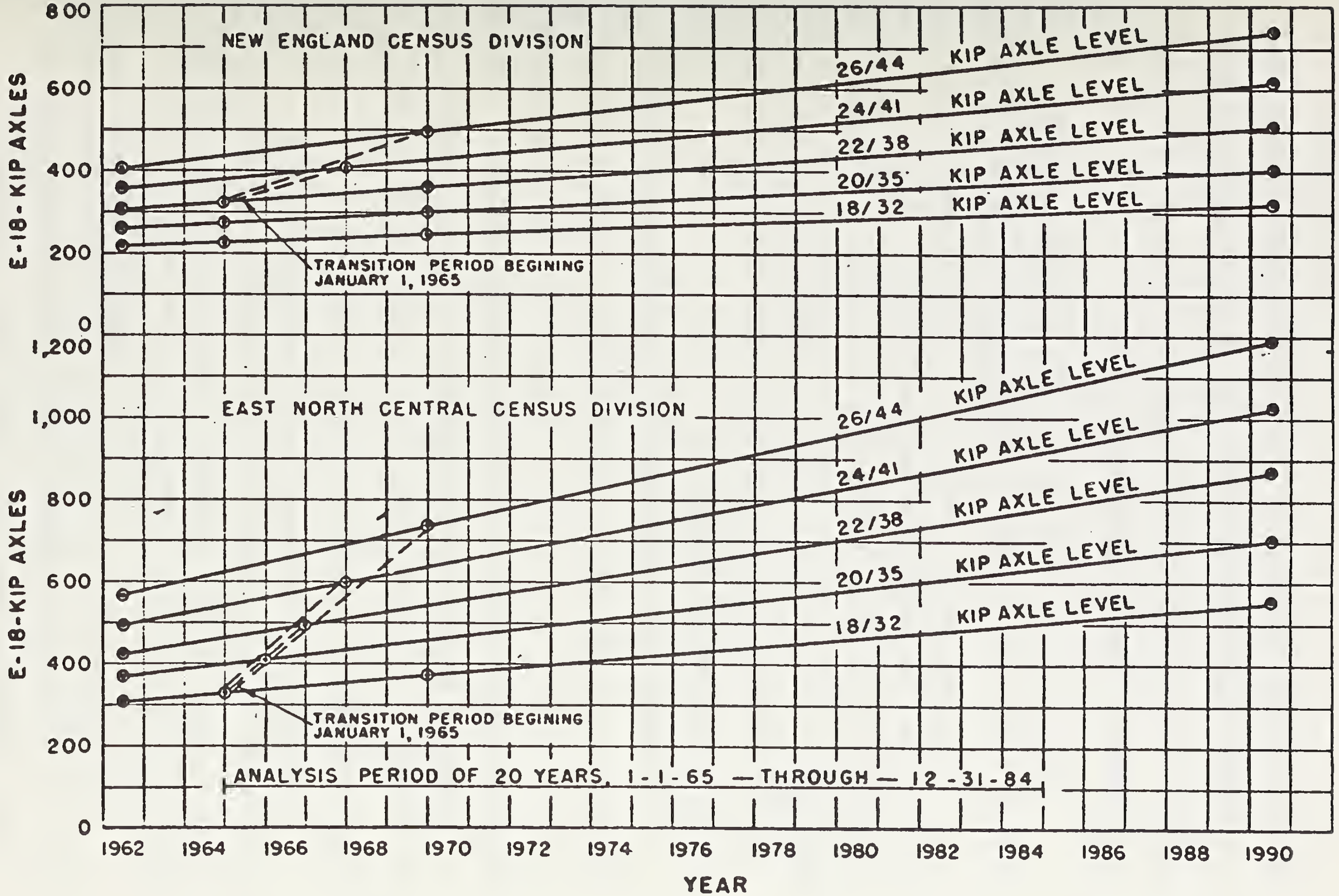


FIG. 10-3. EQUIVALENT 18-KIP AXLE APPLICATIONS FOR HIGHWAY SYSTEM 3, FOR 8 INCH RIGID PAVEMENT

the other States having lower limits and vice versa. Then, with axle-weight distribution for each vehicle class determined for the 18-, 20-, and 22-kip limits, these distribution curves were extrapolated to the 24-kip and 26-kip limits.

Method 1-M was a repeat of Method 1, except minimum pavement depths were imposed. For the lighter traffic volumes, it was found that Method 1 resulted in design pavement depths much less than the States were currently using. These differences resulted not from Method 1 but from the inherent character of the AASHO design formula. Method 1-M was revised, therefore, to produce a pavement depth equal to current designs at current axle-weight limits.

In Method 2 the first step was to plot the 1962 truck weight data by States to show the coordinate relation between the practical maximum gross vehicle weight and the average payload per vehicle by vehicle class. The second step was to plot, by State, the coordinate relation between the 1962 E 18-kip axles by vehicle class and the practical maximum gross vehicle weight. These two curves were extrapolated when necessary.

The data from these two curves were available for calculating the total number of vehicles required to haul the required number of tons of payload, and the number of E 18-kip axle applications applied by each class of vehicle.

Method 8 was the work by the A. T. Kearney Company for the Bureau of Public Roads adapted to the general concept of Method 1 so that equivalent benefit/cost ratios could be compared.

The final benefit-cost ratios produced by Methods 1-M, 2, and 8 were in acceptable agreement with the results obtained by Method 1. But since Method 1-M more nearly reflects current design practices, the 1-M results are preferred to the others. The work by Method 2 is not given in this condensed report.

4. METHOD 1 -- CENSUS-DIVISION-TO-CENSUS-DIVISION TRANSFERENCE OF AXLE-WEIGHT DISTRIBUTIONS

Testing the economy of increasing the legal maximum axle weights of commercial motor vehicles resolves itself into the problem of estimating one basic critical factor: the composition of commercial vehicles (number and type) in the traffic stream under increased axle-weight limits as compared to the composition of traffic at existing limits. Within this factor are two subfactors: (1) axle-weight distributions by single and tandem axles and (2) the gross weight of each vehicle class.

The axle-weight distribution is the necessary factor in calculating the number of equivalent 18,000-pound (E 18-kip) axles, the factor influencing the design of the pavement structure. Gross weight is the key factor in determining the motor vehicle operating cost. The number of vehicles in each vehicle class is required, of course, to compute the total E 18-kip axles and the total operating cost for the ADT (average daily traffic) considered.

A. Basic Concept

Since there is no known procedure by which to estimate the composition of traffic under increased permitted axle-weight limits, logic must be applied to what is now known about existing traffic in order to obtain an estimate. Since there is a range of legal maximum axle weights among the several States, one method of arriving at the traffic composition under increased axle-weight limits is to transfer transport practice in States having high limits to those having lower limits. This procedure of transference was used for axle weights from 18,000 pounds for a single axle and 23,000 pounds for a tandem axle to 22,000 and 38,000 pounds, respectively. By extrapolation the traffic composition and axle-weight distribution were extended to 26/44-kip limits.

B. Axle-Weight Distribution by State Maximum Weight Limits

The axle-weight distributions for each vehicle axle-weight group were assembled by States from the 1962 truck weight study. Based on the legal maximum single-axle weight limit, including tolerances, the States may be grouped as follows:

Single-axle weight groups, pounds	Weight range, pounds	Number of States
18,000	18,000	20
19,000	18,500 - 19,000	10
20,000	19,500 - 20,340	5
22,000	21,600 - 22,400	7 and D. C.
23,000	22,840 - 23,520	4

Grouping of States by Approximate Single-Axle Weight Limits 1/

(*with enforcement tolerance)

18,000 pounds (20 States)

Arizona	Minnesota	South Dakota
California	Mississippi	Tennessee
Idaho	Missouri	Virginia
Illinois	Montana	Washington
Kansas	North Dakota	Utah
Louisiana	Oklahoma	Wyoming
Michigan	Oregon	

19,000 pounds (10 States)

Arkansas	(18,500*)	Kentucky	(18,900*)	Ohio	(19,000)
Iowa	(18,540*)	Nebraska	(18,900*)	Texas	(18,900*)
Indiana	(19,000*)	Nevada	(18,900*)	West Virginia	(18,900*)
		North Carolina	(19,000*)		

20,000 pounds (5 States)

Alabama	(19,800*)	Georgia	(20,340*)	Wisconsin	(19,500*)
Delaware	(20,000)	South Carolina	(20,000)		

22,000 pounds (7 States and D. C.)

District of Columbia	(22,000)	Massachusetts	(22,400)
Florida	(22,000*)	New Mexico	(21,600)
Maine	(22,000)	New York	(22,400)
Maryland	(22,400)	Rhode Island	(22,400)

23,000 pounds (4 States)

Connecticut	(22,848*)	Pennsylvania	(23,072*)
New Jersey	(23,520*)	Vermont	(23,520*)

It was decided to use three major weight groups instead of the five mentioned above. The 19,000- and 23,000-pound groups did not supply sufficient axle-weight data consistent enough to

1/ 1962 data for Colorado (18,000) and New Hampshire (22,400) was not available.

warrant making them separate groups. The three major weight groups selected were made up in the following manner:

18,000 pounds -- The 20 States tabulated above.

20,000 pounds -- 15 States - combining the 19,000-pound and 20,000-pound groups listed above.

22,000 pounds -- 11 States and the District of Columbia - combining the 22,000-pound and 23,000-pound groups listed above.

The axle-weight distribution curves for the single-axle weight groupings of 18,000, 20,000, 24,000, and 26,000 pounds are given in figure 10-2 for the 3-S2 combination for the primary rural highway system (System 3). This set of curves is representative of those for other classes of vehicles and highway systems. The curves for the 24,000- and 26,000- pound axle groups are extrapolated from the three curves for the lower limits. These curves were prepared for each of the seven classes of vehicles and the six highway systems.

C. Distribution of ADT by Vehicle Class, by Census Division, and by Highway System

Since the economy of maximum axle weights depends upon the number of vehicles in the traffic stream and the number of each class of vehicle, it becomes necessary to make the analysis for specific ADT's and for the vehicle-class distribution within

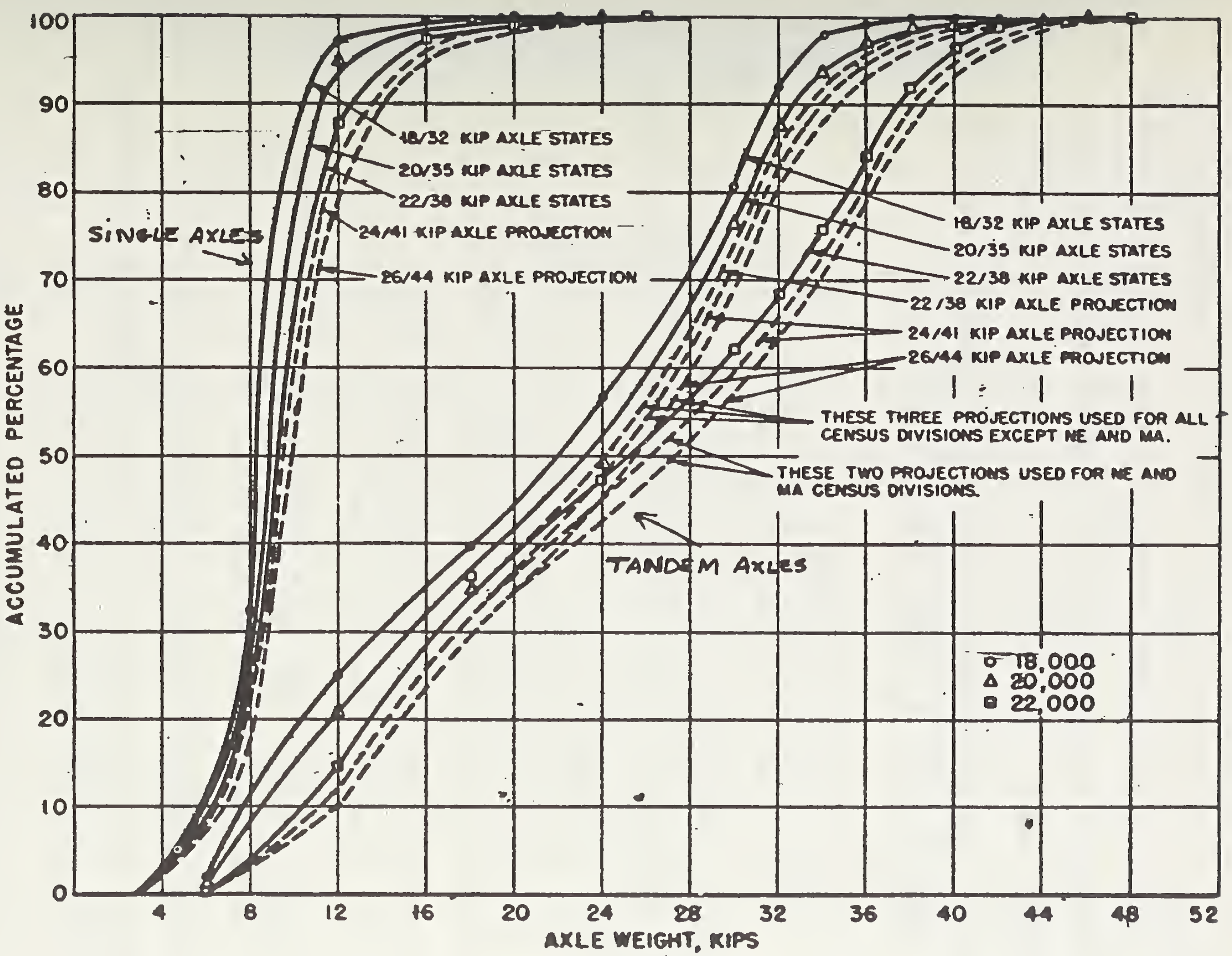


FIGURE 10-2. DISTRIBUTION OF AXLE WEIGHTS OF THE 3-S2 VEHICLE CLASS ON THE PRIMARY RURAL SYSTEM AS SUMMARIZED FROM THE 1962 TRUCK WEIGHT STUDY. SOLID CURVES WITH PLOTTED POINTS ARE AVERAGE OF THOSE STATES HAVING THE INDICATED AXLE WEIGHT LIMITS; DOTTED CURVES ARE EXTRAPOLATED BY JUDGMENT

the ADT. The truck weight studies report the classification of the vehicle stream (vehicles counted) at each weigh station, which may not give the average ADT and vehicle distribution for a specific highway system within a State. For the purposes of this study, the average ADT by highway system was developed for each census division for 1962, as shown in table 10-4.

D. Distribution of Axle Weights

For the most part, computations were based on whole vehicles and whole axles. However, fractional vehicles were used in many instances to compute the number of axles, average payload, and number of vehicles.

As previously stated, the procedure of Method 1 was to adjust the axle-weight distribution for each vehicle class in a census division having a lower maximum limit--such as 18/32 kips--to the distribution found in a census division with a higher limit--such as 20/35 kips. The number of vehicles in each class was then adjusted so that the same total tons of payload were carried by a particular class of vehicle at the limits (base condition) prevailing during the period for which the 1962 truck weight studies were done.

E. Adjustment of the 1962 Base Distribution of Axle Weights to Higher Axle-Weight Levels

The next step was to determine for 1962 the number of vehicles necessary to carry the 1962 total payload at

Table 10-4.--Number of each class of vehicle in the ADT for 1962 and 1990 for each highway system and census division as used in the analysis of the economy of maximum axle-weight limits.

Census division	Year	Pass. car	Buses	Panel and pickup	2S	2D	3A	2-S1	2-S2	3-S2	Comb. 5 axle	2-trailer 5-axle	Total
1. Interstate rural													
1. NE	1962	6,001	32	131	52	216	21.0	126.0	320.0	8.5	-	-	6,907.5
	1990	14,057	49	344	137	423	48.0	201.0	804.0	22.0	-	-	16,085.0
2. MA	1962	6,876	77	183	32	271	32.0	189.0	764.0	67.0	-	-	8,491.0
	1990	16,101	120	478	84	530	75.0	300.0	1,919.0	177.0	-	-	19,784.0
3. SAN	1962	7,634	77	369	68	338	53.0	202.0	1,034.0	23.0	-	-	9,798.0
	1990	18,591	126	1,005	186	688	128.0	336.0	2,704.0	61.0	-	-	23,825.0
4. SAS	1962	5,289	20	374	48	267	53.0	87.0	319.0	40.0	-	-	6,497.0
	1990	14,557	35	1,154	149	616	146.0	164.0	940.0	110.0	-	-	17,871.0
5. ENC	1962	6,763	31	286	48	307	62.0	197.0	601.0	316.0	15	35	8,661.0
	1990	15,823	48	751	126	605	146.0	318.0	1,511.0	954.0	30	81	20,393.0
6. WNC	1962	3,315	24	162	34	139	25.0	44.0	131.0	192.0	-	-	4,066.0
	1990	7,214	34	395	83	254	55.0	67.0	307.0	532.0	-	-	8,941.0
7. ESC	1962	4,638	34	407	44	301	38.0	81.0	472.0	49.0	-	-	6,064.0
	1990	9,733	47	960	104	531	79.0	116.0	1,064.0	131.0	-	-	12,765.0
8. WSC	1962	4,265	32	485	35	224	25.0	129.0	330.0	424.0	-	-	5,949.0
	1990	9,959	51	1,271	91	439	59.0	208.0	829.0	1,273.0	-	-	14,180.0
9. M	1962	3,207	22	289	26	112	19.0	30.0	26.0	135.0	31	18	3,915.0
	1990	8,794	39	890	81	259	53.0	56.0	77.0	478.0	87	51	10,865.0
10. P	1962	7,884	61	917	36	348	62.0	104.0	70.0	278.0	225	320	10,305.0
	1990	24,059	123	3,142	124	892	190.0	219.0	228.0	1,099.0	720	978	31,774.0

Table10-4 .--Number of each class of vehicle in the ADT for 1962 and 1990 for each highway system and census division as used in the analysis of the economy of maximum axle-weight limits.

Sheet 2 of 6

Census division	Year	Pass. car	Buses	Panel and pickup	2S	2D	3A	2-S1	2-S2	3-S2	Comb. 5 axle	2-trailer 5-axle	Total
							2. Interstate urban						
1. NE	1962	14,006	114	938	289	811	79.0	109.0	158.0	5.2	-	-	16,509.2
	1990	45,148	244	3,386	1,046	2,192	254.0	238.0	546.0	15.0	-	-	53,069.0
2. MA	1962	20,767	118	1,256	402	1,284	140.0	168.0	475.0	27.0	-	-	24,637.0
	1990	66,985	253	4,548	1,452	3,471	451.0	364.0	1,640.0	86.0	-	-	79,250
3. SAN	1962	19,436	185	1,038	389	881	84.0	175.0	558.0	23.0	-	-	22,769.0
	1990	65,367	412	3,912	1,469	2,491	282.0	405.0	2,002.0	84.0	-	-	76,424.0
4. SAS	1962	12,439	55	991	114	516	83.0	57.0	212.0	29.0	-	-	14,496.0
	1990	47,134	137	4,221	485	1,646	313.0	143.0	858.0	115.0	-	-	55,052.0
5. ENC	1962	22,652	114	1,121	293	867	132.0	176.0	295.0	217.0	10	8	25,885.0
	1990	73,558	243	4,082	1,066	2,363	429.0	386.0	1,026.0	908.0	25	25	84,111.0
6. WNC	1962	9,501	33	643	156	431	77.0	50.0	100.0	132.0	-	-	11,123.0
	1990	28,738	67	2,183	529	1,097	233.0	104.0	324.0	498.0	-	-	33,773.0
7. ESC	1962	12,357	56	997	953	921	105.0	202.0	661.0	70.0	-	-	16,322.0
	1990	35,733	104	3,238	3,098	2,238	303.0	403.0	2,053.0	260.0	-	-	47,430.0
8. WSC	1962	14,538	59	1,499	243	546	54.0	97.0	179.0	169.0	-	-	17,384.0
	1990	47,481	125	5,505	889	1,498	171.0	217.0	629.0	685.0	-	-	57,200.0
9. M	1962	10,091	31	1,652	245	478	118.0	71.0	35.0	257.0	65	12	13,055.0
	1990	38,083	80	7,001	1,037	1,520	445.0	185.0	140.0	1,187.0	240	45	50,026.0
10. P	1962	22,573	125	2,776	173	1,205	198.0	181.0	114.0	218.0	142	190	27,895.0
	1990	95,571	356	13,194	827	4,285	842.0	522.0	510.0	1,187.0	627	807	118,728.0

Table 10-4.--Number of each class of vehicle in the ADT for 1962 and 1990 for each highway system and census division as used in the analysis of the economy of maximum axle-weight limits.

Sheet 3 of 6

Census division	Year	Pass. car	Buses	Panel and pickup	2S	2D	3A	2-S1	2-S2	3-S2	Comb.5 axle	2-trailer 5-axle	Total
3. Primary rural													
1. NE	1962	3,024	13	146	38	150	18.0	52.0	117.0	4.0	-	-	3,562.0
	1990	3,732	11	201	52	156	23.0	45.0	156.0	6.0	-	-	4,382.0
2. MA	1962	3,269	16	184	61	180	29.0	64.0	275.0	6.0	-	-	4,084.0
	1990	4,026	13	253	85	187	36.0	54.0	364.0	9.0	-	-	5,027.0
3. SAN	1962	3,274	18	247	42	215	35.0	52.0	270.0	9.0	-	-	4,162.0
	1990	4,206	15	356	60	233	45.0	46.0	373.0	13.0	-	-	5,347.0
4. SAS	1962	2,156	9	217	26	156	23.0	30.0	175.0	11.0	-	-	2,803.0
	1990	3,123	9	352	43	190	34.0	30.0	273.0	18.0	-	-	4,072.0
5. ENC	1962	2,596	9	143	35	142	22.0	46.0	135.0	85.0	3	5	3,221.0
	1990	3,211	7	198	49	148	27.0	40.0	180.0	136.0	4	6	4,006.0
6. WNC	1962	1,273	5	95	14	65	15.0	13.0	33.0	50.0	-	-	1,563.0
	1990	1,466	4	123	18	63	17.0	10.0	41.0	73.0	-	-	1,815.0
7. ESC	1962	1,620	12	114	103	136	14.0	33.0	145.0	19.0	-	-	2,196.0
	1990	1,795	8	142	128	127	16.0	26.0	173.0	26.0	-	-	2,441.0
8. WSC	1962	1,735	11	227	26	101	13.0	36.0	92.0	87.0	-	-	2,328.0
	1990	2,154	9	317	36	105	16.0	31.0	123.0	139.0	-	-	2,930.0
9. M	1962	1,019	5	141	8	45	5.0	8.0	8.0	32.0	7	2	1,280.0
	1990	1,473	5	229	13	54	7.0	8.0	13.0	60.0	11	3	1,876.0
10. P	1962	2,575	16	307	12	111	24.0	25.0	16.0	127.0	42	31	3,286.0
	1990	4,130	17	553	21	150	39.0	27.0	29.0	263.0	71	50	5,350.0

Table 10-4.--Number of each class of vehicle in the ADT for 1962 and 1990 for each highway system and census division as used in the analysis of the economy of maximum axle-weight limits.

Sheet 4 of 6

Census division	Year	Pass. car	Buses	Panel and pickup	2S	2D	3A	2-S1	2-S2	3-S2	Comb. 5 axle	2-trailer 5-axle	Total
4. Primary urban													
1. NE	1962	9,196	75	616	190	532	52	71	104	3	-	-	10,839
	1990	14,941	80	1,120	346	725	84	79	180	5	-	-	17,560
2. MA	1962	10,011	57	606	193	619	68	81	229	13	-	-	11,877
	1990	16,276	61	1,104	353	843	109	88	398	20	-	-	19,252
3. SAN	1962	10,387	99	555	208	471	45	94	298	12	-	-	12,169
	1990	17,610	111	1,053	396	671	75	109	539	22	-	-	20,586
4. SAS	1962	7,291	32	581	67	303	49	33	124	17	-	-	8,497
	1990	13,927	40	1,247	143	486	92	42	253	32	-	-	16,262
5. ENC	1962	9,401	47	465	122	360	55	73	123	90	4	3	10,743
	1990	15,388	51	853	224	494	89	80	214	190	5	5	17,593
6. WNC	1962	5,150	18	349	84	233	42	27	54	72	-	-	6,029
	1990	7,851	18	596	144	299	63	28	88	135	-	-	9,222
7. ESC	1962	5,720	26	462	441	426	48	94	306	32	-	-	7,555
	1990	8,337	24	757	721	522	70	94	479	60	-	-	11,064
8. WSC	1962	7,472	30	770	125	281	28	50	92	87	-	-	8,935
	1990	12,299	32	1,424	232	388	45	56	163	176	-	-	14,815
9. M	1962	5,855	18	958	142	277	68	41	21	149	38	7	7,574
	1990	11,137	23	2,047	303	444	130	54	40	365	69	13	14,625
10. P	1962	16,398	91	2,016	126	875	144	132	83	158	103	138	20,264
	1990	34,995	130	4,831	303	1,569	308	191	186	434	230	295	43,472

Table 10-4 .--Number of each class of vehicle in the ADT for 1962 and 1990 for each highway system and census division as used in the analysis of the economy of maximum axle-weight limits.

Sheet 5 of 6

Census division	Year	Pass. car	Buses	Panel and pickup	2S	2D	3A	2-S1	2-S2	3-S2	Comb.5-axle	2-trailer 5-axle	Total
5 & 7. Secondary rural													
1 & 2	1962	933	7	94	16	64	7.5	13.3	20.0	--	--	--	1,154.8
	1990	1,291	6	146	25	75	8.7	12.1	30.2	--	--	--	1,594.0
3 & 4	1962	418	3	71	6	37	4.5	4.5	11.9	--	--	--	555.9
	1990	637	3	123	9	49	5.6	4.5	19.5	--	--	--	850.6
5 to 10	1962	509	4	107	6	33	3.0	4.0	4.0	3	4	4	681.0
	1990	898	5	220	9	47	7.0	4.0	5.0	8	10	8	1,221.0

Table 10-4.--Number of each class of vehicle in the ADT for 1962 and 1990 for each highway system and census division as used in the analysis of the economy of maximum axle-weight limits.

Sheet 6 of 6

Census division	Year	Pass. car	Buses	Panel and pickup	2S	2D	3A	2-S1	2-S2	3-S2	Comb.5 axle	2-trailer 5-axle	Total
6 & 8. Secondary urban													
1. NE	1962	3,464	34	212	97	151	14.0	20.0	25.0	-	-	-	4,017.6
	1990	4,573	29	314	143	166	18.0	18.0	34.2	-	-	-	5,295.2
2. MA	1962	2,873	19	159	75	134	13.0	18.0	41.0	2.5	-	-	3,334.5
	1990	3,796	17	235	111	147	17.0	15.0	57.0	4.3	-	-	4,399.3
3. SAN	1962	3,813	44	186	103	130	11.0	26.0	68.0	2.7	-	-	4,383.7
	1990	5,258	40	289	159	150	15.0	24.0	99.0	4.6	-	-	6,038.6
4. SAS	1962	3,195	17	232	40	100	15.0	13.0	34.0	4.0	-	-	3,650.0
	1990	4,966	17	405	70	130	22.0	13.0	55.0	5.0	-	-	5,683.0
5. ENC	1962	2,841	17	128	50	82	12.0	17.0	23.0	6.0	1	-	3,177.0
	1990	3,790	15	191	75	91	15.0	15.0	32.0	10.0	1	-	4,235.0
6. WNC	1962	1,439	6	89	32	49	8.0	6.0	9.0	6.0	-	-	1,644.0
	1990	1,796	4	124	45	51	10.0	4.0	12.0	7.0	-	-	2,053.0
7. ESC	1962	1,543	8	114	161	87	9.0	19.0	51.0	2.0	-	-	1,944.0
	1990	1,777	6	147	208	83	10.0	15.0	63.0	2.0	-	-	2,311.0
8. WSC	1962	2,942	15	277	67	83	8.0	15.0	22.0	10.0	-	-	3,439.0
	1990	3,946	13	417	101	94	10.0	13.0	32.0	14.0	-	-	4,640.0
9. M	1962	4,192	16	627	138	150	34.0	22.0	9.0	24.0	30	4	5,246.0
	1990	6,511	16	1,095	240	195	52.0	23.0	14.0	48.0	46	6	8,246.0
10. P	1962	4,760	32	534	50	192	29.0	29.0	15.0	10.0	34	38	5,723.0
	1990	8,272	36	1,043	98	280	49.0	34.0	26.0	22.0	60	65	9,985.0

respectively higher axle-weight limits, keeping in mind that heavier empty weights will be employed at these higher weight limits.

The average payload per vehicle computed at this higher weight level was adjusted upward or downward slightly to provide for the same number of tons of payload carried at the base condition. This adjustment was made by arbitrarily shifting axles in the weight distribution from one weight level to another to arrive at the total base payload. Average payloads per vehicle for the various vehicle classes are shown in table 10-4A.

The total payload carried by all vehicles of the class was then divided by the average payload per vehicle to arrive at the number of vehicles at the higher weight level.

This same procedure was continued for each vehicle type, census division, weight level, and highway system.

F. Calculation of the Axle-Weight Distribution and Number of Vehicles for 1990

The procedure for computing the payload and gross weights carried in the year 1990 was similar to that used for the 1962 computation but with a slightly different method for adjusting the payload. First of all, the tables in the series on average payloads expected in 1990 for all vehicle classes show a 29-percent increase in average payload per vehicle. This payload increase was used throughout the analysis for all computations to 1990.

Table 10-4A .--Average payload, empty, and gross weights of each class of vehicle in Method 1
East North Central--primary, rural

Vehicle Class	Weight Pounds	Method 1 (year 1982) Single/tandem maximum axle-weight limits, kips					Method 1 (year 1990) Single/tandem maximum axle-weight limits, kips				
		18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
2D	Payload	4,235	3,986	3,855	3,735	3,594	4,235	4,003	3,873	3,753	3,612
	Empty weight	9,220	9,510	9,800	10,090	10,390	9,220	9,510	9,800	10,090	10,390
	Gross weight	13,455	13,496	13,655	13,825	13,984	13,455	13,513	13,673	13,843	14,002
3A	Payload	9,227	10,155	11,328	11,953	12,675	11,903	12,858	13,974	15,305	16,070
	Empty weight	15,635	17,795	19,950	22,105	24,260	15,635	17,795	19,950	22,105	24,260
	Gross weight	24,862	27,950	31,278	34,058	36,935	27,538	30,651	33,924	37,410	40,330
2-S1	Payload	8,365	8,951	9,390	10,118	10,675	10,791	11,665	12,331	13,079	13,923
	Empty weight	18,950	20,200	21,450	22,700	23,950	18,950	20,200	21,450	22,700	23,950
	Gross weight	27,315	29,151	30,840	32,818	34,625	29,741	31,865	33,781	35,779	37,873
2-S2	Payload	16,020	16,505	17,298	18,482	19,659	20,666	21,257	22,275	23,846	25,305
	Empty weight	23,550	24,800	26,050	27,300	28,550	23,550	24,800	26,050	27,300	28,550
	Gross weight	39,570	41,305	43,348	45,782	48,209	44,216	46,057	48,325	51,146	53,855
3-S2	Payload	22,027	23,399	25,300	27,939	30,703	28,415	30,191	32,749	36,116	39,433
	Empty weight	28,190	30,570	32,950	35,330	37,710	28,190	30,570	32,950	35,330	37,710
	Gross weight	50,217	53,969	58,250	63,269	68,413	56,605	60,761	65,699	71,446	77,143
3-2	Payload	32,167	31,467	32,100	32,067	47,950	41,495	41,500	41,500	41,500	55,333
	Empty weight	26,000	26,700	27,400	28,100	28,800	26,000	26,700	27,400	28,100	28,800
	Gross weight	58,167	58,167	59,500	60,167	76,750	67,495	68,200	68,900	69,600	84,133
3-4	Payload	--	--	--	--	--	--	--	--	--	--
	Empty weight	--	--	--	--	--	--	--	--	--	--
	Gross weight	--	--	--	--	--	--	--	--	--	--
2-S1-2	Payload	26,000	25,900	26,000	32,450	32,325	33,540	33,533	33,533	40,240	40,240
	Empty weight	28,500	29,400	30,300	30,800	31,300	28,500	29,400	30,300	30,800	31,300
	Gross weight	54,500	55,300	56,300	63,250	63,625	62,040	62,933	63,833	71,040	71,540
3-S2-3	Payload	--	--	--	--	--	--	--	--	--	--
	Empty weight	--	--	--	--	--	--	--	--	--	--
	Gross weight	--	--	--	--	--	--	--	--	--	--
3-S2-4	Payload	--	--	--	--	--	--	--	--	--	--
	Empty weight	--	--	--	--	--	--	--	--	--	--
	Gross weight	--	--	--	--	--	--	--	--	--	--

The base 1990 ADT for each vehicle class was available for each highway system. Therefore, the base ADT's for 1962 and 1990 and the 1962 ADT for each higher axle-weight limit were available. The 1990 ADT's for each vehicle class at higher axle-weight limits were computed from the following relationship: the ADT at 1962 base condition is to the ADT at 1990 base condition as the 1962 ADT at each higher weight level is to the 1990 ADT at the same weight level.

5. DESIGN OF PAVEMENT STRUCTURE

For analysis of the economy of changes both in maximum axle-weight limits and in the maximum limits on vehicle dimensions, the design of the pavement structure was based upon the "AASHO Interim Guide for the Design of Flexible Pavement Structures" (October 12, 1961) and "Rigid Pavement Structures" (April 1962). The pavement design guides were developed from the AASHO Road Test results. The design procedure and selection of the factors involved are described as each was applied to the 10 census divisions and the highway systems. The main factors in the design formulas are as follows:

(1) Number of applications to the pavement of equivalent 18,000-pound axles (E 18-kip axles)

(2) Terminal value of the present serviceability index (PSI or P_t)

(3) Soil support values

A. General Provisions

The pavement was designed for a period of 20-years, January 1, 1965 to December 31, 1984. The terminal PSI of 2.0 was used for all highway systems, all ADT's, and both types of pavements. Although a PSI value of 2.5 might be more suitable for the high-volume Interstate routes, the 2.0 figure was used to keep all design factors constant, because it was desirable to obtain comparable results between systems and ADT's.

For 2-lane, bi-directional highways, the traffic was assumed to be equally divided between the lanes. For 4-lane divided highways, the total ADT was assumed to be 50 percent in each direction, but with 80 percent of the total E 18-kip axle applications in each direction on the right-hand lane of each pair of lanes. See tables 10-5 and 10-6.

B. Soil Support for Rigid and Flexible Pavements

A representative soil support value was assigned to each census division (table 10-7) by judging relatively the general soil condition in one division against another.

C. Rigid Pavement Design

New rigid pavements were designed using the following assumptions:

(1) The initial serviceability index of the pavement is 4.5, the value obtained in the AASHO Road Test.

(2) The terminal serviceability index of the pavement is P = 2.0.

Table 10-5. -- Average daily traffic-volume guide to number of lanes

Number of lanes	ADT range	Nominal maximum ADT	
		Interstate system	Primary system
		Rural freeways	Rural highways
2	0 - 6,000	4,500	3,000
4	up to 27,000	21,000	18,000
6	up to 40,000	31,000	26,000
8	up to 54,000	42,000	--
		Urban freeways	Urban highways
4	up to 56,000	40,000	10,000
6	up to 84,000	60,000	15,000
8	up to 112,000	80,000	20,000
10	up to 140,000	100,000	--

Table 10-6.--Summary of number of lanes
for each highway system and census division

Census division	1. Inter-state rural	2. Inter-state urban	3. Pri-mary rural	4. Pri-mary urban	5. Secon-dary rural	6. Secon-dary urban
1. NE	4	4	4	4	2	2
2. MA	4	4	4	4	2	2
3. SAN	4	4	4	4	2	2
4. SAS	4	4	4	4	2	2
5. ENC	4	4	4	4	2	2
6. WNC	4	[illegible]	2	2	2	2
7. ESC	4	4	2	2	2	2
8. WSC	4	4	2	2	2	2
9. M	4	4	2	2	2	2
10. P	4	4	4	4	2	2

Table 10-7. -- Representative average soil support values used for the design of pavements

Census division	Rigid pavement modulus of subgrade reaction (k)	Flexible pavement soil support values
1. New England	150	5.0
2. Middle Atlantic	150	5.0
3. South Atlantic North	100	3.7
4. South Atlantic South	200	6.0
5. East North Central	100	3.7
6. East South Central	150	5.0
7. West North Central	100	3.7
8. West South Central	100	3.7
9. Mountain	250	7.3
10. Pacific	200	6.0

(3) The modulus of subgrade reaction (k) was chosen for each census division as given in table 10-7.

(4) The modulus of elasticity of concrete is 4,200,000 PSI.

(5) The modulus of rupture of the concrete is 650 PSI and the working stress is 3/4 x 650 = 487.5 PSI.

(6) The pavements have jointed slabs with adequate load transfer devices.

D. Base Design for Rigid Pavements

A study of State practice indicates that the thickness and qualities of base materials currently being used on Interstate and primary highways are about as shown in table 10-8, in which the values represent practices within each census division. The AASHO Road Test shows that rigid pavements with granular bases performed better than those without, but no significant differences were observed for 3, 6, or 9 inches of such base material. This and the fact that granular bases are used for insulation indicate that increase in base thicknesses in the future is doubtful. However, a trend toward better quality of granular base material through stabilization is currently raising the cost of bases for rigid pavements.

E. Flexible Pavement Design

New flexible pavements were designed using the "AASHO Interim guide for the Design of Flexible Pavement Structures" (October 12, 1961) with the following assumptions:

Table 10-8. -- Granular base thickness and material for rigid pavement

Census division	Thickness of base	Type of material	Comment 1/	Material used in analysis for economy of axle weight 2/
	inches			
1. NE	3/ 19	open-graded gravel	drained	clay-gravel
2. MA	11	open-graded gravel	drained	clay-gravel
3. SAN	8	dense-graded granular		clay-gravel
4. SAS	6	stabilized granular		stone-macadam
5. ENC	8	open-graded granular	drained	stone-macadam
6. WNC	6	dense-graded sand-gravel	drained	stone-macadam
7. ESC	8	dense-graded crushed aggregate	drained	stone-macadam
8. WSC	10	stabilized selected local material		clay-gravel
9. M	6	cement-stablilized granular		clay-gravel
10. P	8	dense-graded	drained	stone-macadam

1/ Drained full width in fill or underdrains in cut.

2/ Clay-gravel or stone macadam used in the analysis because of availability of a price-curve based on thickness. Clay-gravel or stone macadam selected on basis of total cost and on suitability and not on availability.

3/ Ten inches added for frost protection.

(1) The initial serviceability index of the pavement is 4.2, the value obtained on the AASHO Road Text.

(2) The terminal serviceability index of the pavement is P = 2.0.

(3) The soil support value for each census division is as given in table 10-7.

(4) The regional factor is 1.0.

(5) The strength coefficients of the different courses are:

a. Surface = 0.44

b. Granular base = 0.14

c. Subbase = 0.11

The depth of each layer (base, subbase, and bituminous concrete surface) was computed in accordance with the design procedure by the use of an electronic computer.

F. Subbase for Flexible Pavements

All the flexible pavement designs in the present size and weight study are composed of layers of surfacing, base, and subbase material. The thicknesses of these components were derived from the AASHO equations and are adequate to carry the expected traffic over the next 20 years (1965 through 1984).

G. Computation of E 18-Kip Axle Applications

The "AASHO Interim Guide for Pavement Design" gives the factors for reducing axle loads to equivalent 18-kip single-axle applications. These factors are given as extended to higher axle-weight limits in Appendix B.

For rigid pavements these equivalence factors vary by a minor amount with the slab thickness; and for flexible pavements, with the structural number (SN). The SN factor varies with the soil support value and the daily number of applications of equivalent 18-kip single axles. For both types of pavements, the equivalence factors vary with the terminal PSI, or P_t value, the factors being slightly larger for a smaller value of P_t.

To simplify the many calculations for the economy of maximum axle weight, the E 18-kip axles for rigid pavements were all calculated for a slab of 8 inches, regardless of the calculated final slab thickness. Also, for flexible pavements a structural number of 3 was used for all calculations of the E 18-kip axles. For the purpose of calculating the relative economy of the maximum axle-weight limits, these two departures from strict design procedure introduce no significant errors in the finally resulting relative pavement costs.

H. Calculation of the Pavement Structure Depths and Construction Cost

The depths of the pavement surface, base, and subbase and the construction cost were calculated using a computer program so written that it could produce the following items:

(1) The accumulated total of E 18-kip axle applications for the 20 years from 1965 through 1984.

(2) The thickness of the rigid pavement slab and the thickness of each of the three courses for the flexible pavement structure.

(3) The cubic yards of each type of material in one highway mile, including the shoulders.

(4) The price per cubic yard of the specific thicknesses of pavement courses from the equations of the price curves (See table 8-2, page 8-12.).

(5) The total dollar cost per highway mile, including the appropriate base material for rigid pavement.

See figure 10-3 (page 10-9) for the E 18-kip axle curves for the New England and East North Central census divisions.

6. CONSTRUCTION COST OF THE HIGHWAY AS AFFECTED BY AXLE-WEIGHT LIMITS

In the final analysis, the total highway cost at each of the five levels of axle-weight limit was compared with the operating cost of those vehicles whose costs would be affected by a change in legal axle-weight limits. The elements of highway construction cost affected by axle-weight limits are as follows: (1) pavement and shoulders, (2) bridges, and (3) earthwork and small drainage structures. These costs were computed for a mile of new highway, as explained in the following sections.

A. Pavement Geometric Design

Figure 10-4 shows the standard designs of the highway cross section adopted for purposes of estimating the total cost of the pavement and shoulder structure for the series of axle-weight increments considered in the analysis of the engineering economy of increased axle-weight limits.

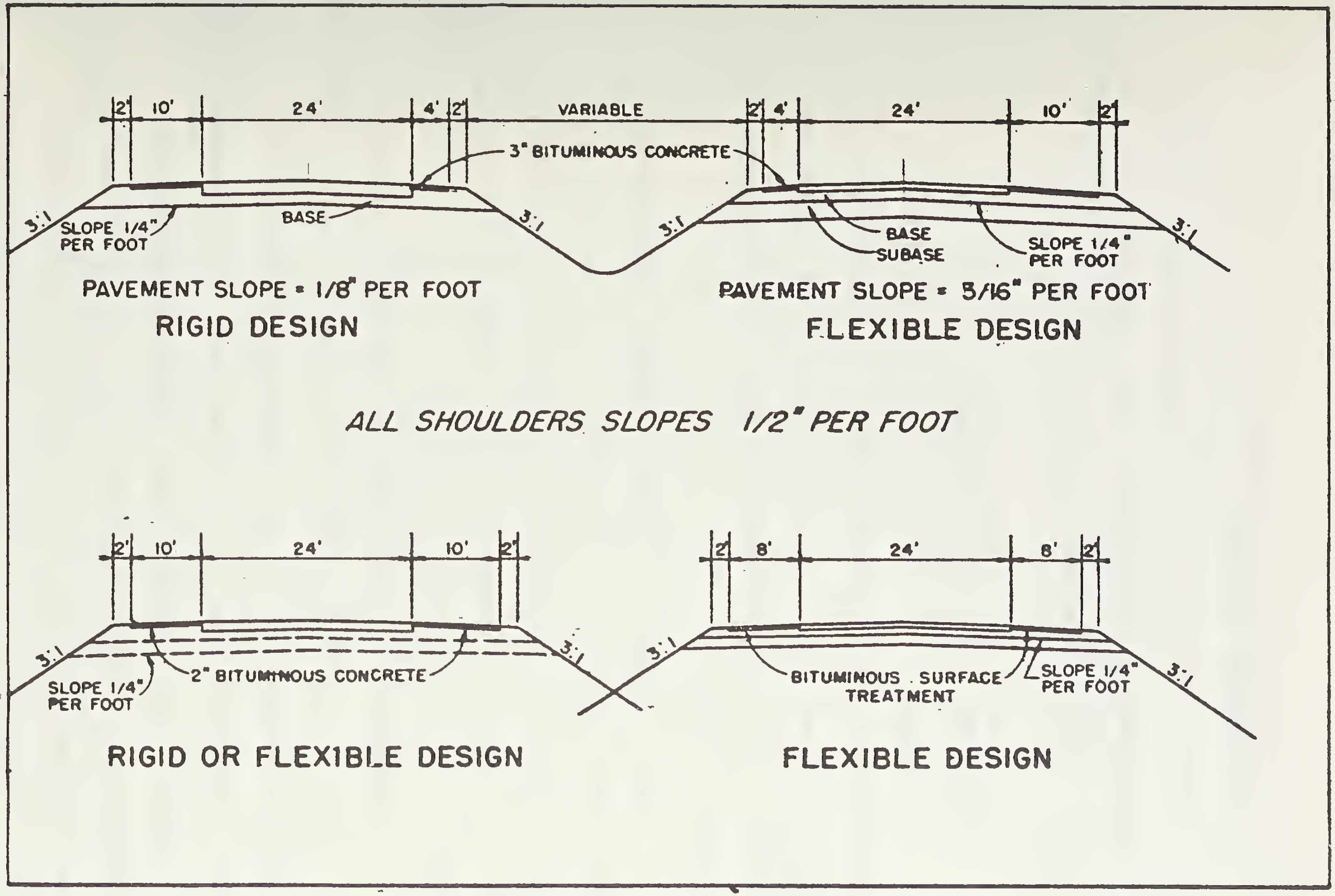


FIGURE 10-4. GEOMETRIC CROSS SECTION OF ROADWAYS USED IN THE AXLE WEIGHT ECONOMY ANALYSES

B. Unit Price and Construction Cost of the Pavement Structure

The unit prices of the paving materials given in table 8-2 were applied to the quantities (cubic yards per mile) as computed from the cross sections in figure 10-4.

C. Construction Cost of Bridges Related to Increments of Maximum Axle Weight

The approach to determining the cost of bridges to accommodate traffic at the five levels of maximum axle-weight limit considered only steel bridges designed for the standard H20-S16 loading, but was based upon each of the five levels of axle-weight limit.

Table 10-9 gives the critical vehicles for a range of bridge span length from 20 to 140 feet. From the loadings of these vehicles were developed the pounds of steel required for the five levels of maximum axle weight. Table 10-10 shows the required steel by span length of bridge.

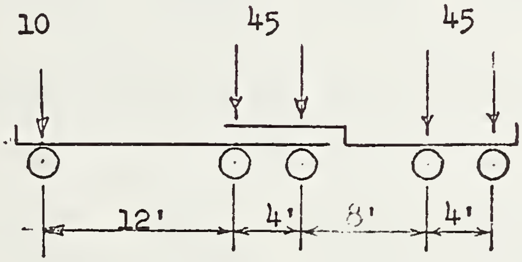
The upper half of the table was developed on the basis of structural design for the indicated span lengths. Because of change in the geometrics of the bridges, the increase in the added increments of steel required per lineal foot of bridge is not smooth over the range of weight limits. In preliminary calculations it was found that the lack of uniform increments of steel resulted in undesirable roughness from one axle-weight level to another in the final highway cost increments and in the

Table 10-9. -- Critical vehicles

Span, feet	No gross Load limit	100-kip gross load limit Proposed axle loads, kips				
		18/32	20/35	22/38	24/41	26/44
20	3-S2	3-S2	3-S2	3-S2	3-S2	3-S2
30	"	"	"	"	"	"
40	"	"	"	"	"	"
50	3-S2-3	3-S2-3	"	"	"	"
60	"	"	3-S2-3	"	"	"
70	"	"	"	3-S2-3	"	"
80	"	"	"	"	"	"
90	"	"	"	"	"	"
100	"	"	"	"	"	"
110	"	"	"	"	3-S2-3	"
120	"	"	"	"	"	"
130	"	"	"	"	"	"
140	"	"	"	"	"	"

Percent of distribution of gross load

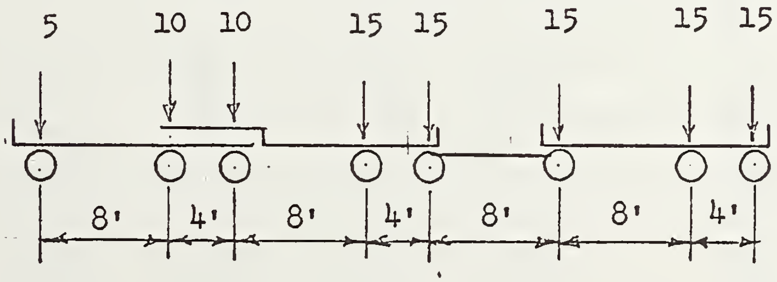
Axle spacing



3-S2

Percent of distribution of gross load

Axle spacing



3-S2-3

Table 10-10. -- Structural steel required per linear foot of 2-lane bridge for proposed higher axle-weight limits: increments of pounds of steel by span length of bridge required above the H20-S16 design loading

Span length	Single/tandem axle-weight limits, kips				
	18/32	20/35	22/38	24/41	26/44
Additional pounds per linear foot of bridge obtained from structural analysis					
Feet	lb.	lb.	lb.	lb.	lb.
20	7.5	24.0	39.5	56.0	72.0
30	41.0	61.5	82.5	104.0	125.0
40	61.0	88.5	116.0	144.0	171.0
50	172.0	233.5	299.5	357.0	417.5
60	264.0	330.0	397.5	458.0	526.0
70	275.0	288.0	334.0	422.5	473.5
80	52.6	109.0	144.6	207.6	217.9
90	130.6	179.9	299.2	289.3	327.8
100	141.3	201.5	233.0	279.1	314.3
110	136.5	181.6	213.2	269.0	314.2
120	122.4	166.8	220.7	271.3	329.0
130	125.6	176.1	226.9	277.4	313.4
140	137.2	194.7	237.9	292.0	356.7
The above structural design smoothed to straight lines					
20	7.5	23.6	39.8	55.9	72.0
30	41.0	62.0	83.0	104.0	125.0
40	61.0	88.5	116.0	143.5	171.0
50	172.0	233.4	294.8	356.1	417.5
60	264.0	329.5	395.0	460.5	526.0
70	226.2	288.0	350.0	411.7	473.5
80	72.7	109.0	145.3	181.6	217.9
90	130.6	179.9	229.2	278.5	327.8
100	141.3	187.2	233.0	278.8	324.7
110	133.4	178.6	223.8	269.0	314.2
120	119.5	170.1	220.7	271.3	321.9
130	125.6	176.2	226.8	277.4	328.0
140	146.0	194.7	243.4	292.0	340.6
140 and over	160.0	210.0	260.0	310.0	360.0
Total	1,800.8	2,430.7	3,060.8	3,690.3	4,320.1

final benefit-cost ratios. Because the final benefit-cost ratios were highly sensitive to several factors, including highway construction cost per mile, it was thought to be better procedure to remove the abrupt changes in bridge cost between some axle-weight levels by smoothing the pounds of steel required from one weight level to another.

The additional pounds of steel required for the increased axle-weight limits was determined by comparing the inventory of bridges by span length (see table 8-8) against the incremental steel requirement given in table 10-10 to produce the overall pounds of steel required per foot of length of bridge for a 2-lane roadway, using the standard H20-S16 basic design (see table 10-11). These pounds of steel per foot of bridge length for a 2-lane roadway were converted to pounds of structural steel per mile of highway by multiplying by the length of bridges per mile of 2-lane highway as given in table 10-12 and then multiplying by one-half of the number of lanes. For the five axle-weight levels, table 10-13 gives per mile of highway the final pounds of structural steel in excess of the pounds required for a standard H20-S16 design, by highway system and census division.

By analysis of Federal-aid construction contracts for 1962 and 1963, the average bid price per pound of structural steel was obtained for each census division. These prices are given in table 8-4, page 8-14. In table 10-14, the cost of constructing bridges in excess of the standard H20-S16 design was computed for

Table 10-11. -- Structural steel required per linear foot of 2-lane bridge for proposed higher axle-weight limits: increments of pounds of steel per bridge above the H20-S16 design loading, weighted by span length and shown by highway system and census division

Sheet 1 of 3

Census division	Number of lanes	Maximum axle-weight limits, single/tandem, kips				
		18/32	20/35	22/38	24/41	26/44
System 1. Interstate rural						
1. NE	4	137.920	183.761	229.601	275.442	321.282
2. MA	4	137.937	183.647	229.358	275.068	320.778
3. SAN	4	137.937	183.647	229.358	275.068	320.778
4. SAS	4	123.179	166.628	210.076	253.525	296.973
5. ENC	4	137.163	182.720	228.278	273.835	319.392
6. WNC	4	123.161	165.332	207.502	249.673	291.843
7. ESC	4	150.012	198.726	247.441	296.155	344.869
8. WSC	4	74.737	105.555	136.373	167.191	198.009
9. M	4	91.312	126.195	161.077	195.960	230.842
10. P	4	138.502	184.916	231.330	277.743	324.157
System 2. Interstate urban						
1. NE	4	151.324	199.811	248.297	296.784	345.270
2. MA	4	144.711	192.449	240.187	287.925	335.663
3. SAN	4	151.628	201.357	251.086	300.815	350.544
4. SAS	4	143.450	190.400	237.351	284.301	331.251
5. ENC	4	161.666	212.712	263.758	314.803	365.849
6. WNC	4	162.216	213.984	265.751	317.519	369.286
7. ESC	4	135.865	181.750	227.636	273.521	319.406
8. WSC	4	117.210	157.945	198.679	239.414	280.148
9. M	4	115.788	156.470	197.152	237.834	278.516
10. P	4	145.659	192.771	239.882	286.994	334.105

Table 10-11. -- Structural steel required per linear foot of 2-lane bridge for proposed higher axle-weight limits: increments of pounds of steel per bridge above the H20-S16 design loading, weighted by span length and shown by highway system and census division

Sheet 2 of 3

Census division	Number of lanes	Maximum axle-weight limits, single/tandem, kips				
		18/32	20/35	22/38	24/41	26/44
System 3. Primary rural						
1. NE	4	112.434	152.194	191.955	231.715	271.475
2. MA	4	98.481	135.380	172.278	209.177	246.075
3. SAN	4	106.491	145.144	183.737	222.359	260.982
4. SAS	4	58.578	85.998	113.418	140.835	168.258
5. ENC	4	109.808	148.902	187.996	227.090	266.184
6. WNC	2	83.630	116.604	149.578	182.552	215.526
7. ESC	2	66.413	95.701	124.988	154.276	183.563
8. WSC	2	47.951	72.655	97.359	122.062	146.766
9. M	2	57.242	84.230	111.219	138.207	165.195
10. P	4	109.584	148.815	188.046	227.276	266.507
System 4. Primary urban						
1. NE	4	94.510	130.513	166.516	202.519	238.522
2. MA	4	109.566	148.879	188.192	227.504	266.817
3. SAN	4	124.601	167.473	210.346	253.218	296.090
4. SAS	4	73.827	104.474	135.120	165.767	196.413
5. ENC	4	154.791	204.130	253.468	302.806	352.145
6. WNC	2	93.804	129.671	165.539	201.406	237.273
7. ESC	2	66.413	95.701	124.988	154.276	183.563
8. WSC	2	97.053	133.323	169.593	205.863	242.133
9. M	2	84.871	118.275	151.679	185.082	218.486
10. P	4	115.543	156.855	198.166	239.478	280.789

Table 10-11. -- Structural steel required per linear foot of 2-lane bridge for proposed higher axle-weight limits: increments of pounds of steel per bridge above the H20-S16 design loading, weighted by span length and shown by highway system and census division

Sheet 3 of 3

Census division	Number of lanes	Maximum axle-weight limits, single/tandem, kips				
		18/32	20/35	22/38	24/41	26/44
System 5. Secondary rural						
1. NE	2	102.637	140.428	118.217	216.006	253.796
2. MA	2	101.764	139.501	177.238	214.975	252.712
3. SAN	2	118.597	159.859	201.121	242.382	283.644
4. SAS	2	80.685	113.332	145.978	178.625	211.271
5. ENC	2	122.324	164.578	206.832	249.086	291.340
6. WNC	2	60.625	88.069	115.513	142.957	170.401
7. ESC	2	80.142	112.354	144.566	176.777	208.989
8. WSC	2	34.259	55.977	77.694	99.412	121.129
9. M	2	35.201	57.577	79.954	102.330	124.706
10. P	2	80.916	113.567	146.218	178.869	211.520
System 6. Secondary urban						
1. NE	2	86.685	120.802	154.920	189.037	223.154
2. MA	2	82.215	115.195	148.175	181.154	214.134
3. SAN	2	116.355	157.174	197.993	238.811	279.630
4. SAS	2	84.731	118.105	151.479	184.852	218.226
5. ENC	2	138.609	184.510	230.411	276.312	322.213
6. WNC	2	90.505	125.340	160.175	195.010	229.845
7. ESC	2	69.801	99.358	128.916	158.473	188.030
8. WSC	2	96.717	132.763	168.810	204.856	240.902
9. M	2	70.601	100.649	130.698	160.746	190.794
10. P	2	120.358	161.782	203.205	244.629	286.052

Table 10-12. -- Total length of bridges in feet per mile and construction cost in dollars per mile of highway, by highway system and census division

Sheet 1 of 3

Highway system and census division	Total bridge length per mile of highway	Cost of bridges per mile of highway
1. Interstate rural		
	Feet	Dollars
1. NE	198	256,750
2. MA	511	320,856
3. SAN	250	275,157
4. SAS	142	128,254
5. ENC	147	219,336
6. WNC	124	109,681
7. ESC	199	142,701
8. WSC	259	169,197
9. M	86	83,272
10. P	177	175,141
2. Interstate urban		
1. NE	219	1,876,665
2. MA	396	2,212,649
3. SAN	483	1,974,658
4. SAS	155	493,561
5. ENC	163	1,473,526
6. WNC	157	990,702
7. ESC	228	1,162,574
8. WSC	232	641,727
9. M	114	417,723
10. P	200	1,545,987

Table 10-12. -- Total length of bridges in feet per mile and construction cost in dollars per mile of highway, by highway system and census division

Sheet 2 of 3

Highway system and census division	Total bridge length per mile of highway	Cost of bridges per mile of highway
3. Primary rural		
	Feet	Dollars
1. NE	49	54,765
2. MA	36	43,955
3. SAN	61	27,791
4. SAS	70	21,651
5. ENC	30	25,368
6. WNC	45	15,724
7. ESC	73	31,230
8. WSC	68	20,909
9. M	26	13,172
10. P	50	41,024
4. Primary urban		
1. NE	149	181,854
2. MA	98	172,434
3. SAN	148	122,082
4. SAS	120	108,301
5. ENC	93	136,938
6. WNC	48	35,639
7. ESC	103	42,934
8. WSC	99	53,870
9. M	34	36,602
10. P	208	259,935

Table 10-12. -- Total length of bridges in feet per mile and construction cost in dollars per mile of highway, by highway system and census division

Sheet 3 of 3

Highway system and census division	Total bridge length per mile of highway	Cost of bridges per mile of highway
5. Secondary rural		
	Feet	Dollars
1. NE	13	19,946
2. MA	15	15,357
3. SAN	14	6,368
4. SAS	37	4,741
5. ENC	13	5,863
6. WNC	19	4,393
7. ESC	50	11,687
8. WSC	39	6,392
9. M	14	6,464
10. P	17	7,478
6. Secondary urban		
1. NE	378	68,221
2. MA	413	60,540
3. SAN	327	28,296
4. SAS	621	23,578
5. ENC	411	31,548
6. WNC	196	10,052
7. ESC	719	159,412
8. WSC	560	9,408
9. M	179	18,199
10. P	728	47,529

Table 10-13. -- Pounds of structural steel per mile of highway, excess over standard H20-S16 design

Sheet 1 of 2

Census division	18/32	20/35	22/38	24/41	26/44
System 1. Interstate rural					
1. NE	54,616	72,769	90,922	109,075	127,228
2. MA	140,972	187,687	234,404	281,119	327,835
3. SAN	68,969	91,824	114,679	137,534	160,389
4. SAS	34,983	47,322	59,662	72,001	84,340
5. ENC	40,326	53,720	67,114	80,507	93,901
6. WNC	30,544	41,002	51,460	61,919	72,377
7. ESC	59,705	79,093	98,482	117,870	137,258
8. WSC	38,714	54,677	70,641	86,605	102,569
9. M	15,706	21,706	27,705	33,705	39,705
10. P	49,030	65,460	81,891	98,321	114,752
System 2. Interstate urban					
1. NE	66,280	87,517	108,754	129,971	151,228
2. MA	114,611	152,420	190,228	228,037	265,845
3. SAN	146,473	194,511	242,549	290,587	338,626
4. SAS	44,470	59,024	73,579	88,133	102,688
5. ENC	52,703	69,344	85,985	102,626	119,267
6. WNC	50,936	67,191	83,446	99,701	115,956
7. ESC	61,954	82,878	103,802	124,726	145,649
8. WSC	54,385	73,286	92,187	111,088	129,989
9. M	26,400	35,675	44,951	54,226	63,502
10. P	58,264	77,108	95,953	114,798	133,642
System 3. Primary rural					
1. NE	11,019	14,915	18,812	22,708	26,605
2. MA	7,091	9,747	12,404	15,061	17,717
3. SAN	12,992	17,708	22,416	27,128	31,840
4. SAS	8,201	12,040	15,879	19,717	23,556
5. ENC	6,588	8,934	11,280	13,625	15,971
6. WNC	3,763	5,247	6,731	8,215	9,698
7. ESC	4,848	6,986	9,124	11,262	13,400
8. WSC	3,260	4,940	6,620	8,300	9,980
9. M	1,488	2,190	2,891	3,593	4,295
10. P	10,958	14,882	18,805	22,728	26,651

Table 10-13. -- Pounds of structural steel per mile of highway, excess over standard H20-S16 design

Sheet 2 of 2

Census division	18/32	20/35	22/38	24/41	26/44
System 4. Primary urban					
1. NE	28,164	38,893	49,622	60,351	71,080
2. MA	21,475	29,180	36,886	44,591	52,296
3. SAN	36,882	49,572	62,262	74,953	87,643
4. SAS	17,718	25,074	32,429	39,784	47,139
5. ENC	28,791	37,968	47,145	56,322	65,499
6. WNC	4,502	6,224	7,946	9,667	11,389
7. ESC	6,840	9,857	12,874	15,890	18,907
8. WSC	9,608	13,199	16,789	20,380	23,971
9. M	2,885	4,021	5,157	6,293	7,428
10. P	48,066	65,252	82,437	99,623	116,808
System 5. Secondary rural					
1. NE	1,334	1,826	2,317	2,808	3,299
2. MA	1,526	2,093	2,659	3,225	3,791
3. SAN	1,660	2,238	2,816	3,393	3,971
4. SAS	2,985	4,193	5,401	6,609	7,817
5. ENC	1,590	2,140	2,689	3,238	3,787
6. WNC	1,152	1,673	2,195	2,716	3,238
7. ESC	4,007	5,618	7,228	8,839	10,449
8. WSC	1,336	2,183	3,030	3,877	4,724
9. M	493	806	1,119	1,433	1,746
10. P	1,376	1,931	2,486	3,041	3,596
System 6. Secondary urban					
1. NE	32,767	45,663	58,560	71,456	84,352
2. MA	33,955	47,576	61,196	74,817	88,437
3. SAN	38,048	51,396	64,744	78,091	91,439
4. SAS	52,618	73,343	94,068	114,793	135,518
5. ENC	56,968	75,834	94,699	113,564	132,430
6. WNC	17,739	24,567	31,394	38,222	45,050
7. ESC	50,187	71,438	92,691	113,942	135,194
8. WSC	54,162	74,347	94,534	114,719	134,905
9. M	12,638	18,016	23,395	28,774	34,152
10. P	87,621	117,777	147,933	178,090	208,246

Table 10-14. -- Dollars of construction cost for structural steel per mile of highway, excess of cost over standard H20-S16 design

Sheet 1 of 2

Census division	18/32	20/35	22/38	24/41	26/44
System 1. Interstate rural					
1. NE	9,240	12,312	15,384	18,455	21,527
2. MA	25,897	34,478	43,060	51,642	60,223
3. SAN	11,627	15,482	19,335	23,188	27,042
4. SAS	4,884	6,606	8,329	10,051	11,774
5. ENC	6,400	8,525	10,651	12,776	14,902
6. WNC	6,176	8,291	10,405	12,520	14,635
7. ESC	11,565	15,320	19,076	22,831	26,587
8. WSC	6,206	8,765	11,324	13,883	16,442
9. M	3,331	4,604	5,876	7,149	8,421
10. P	11,787	15,737	19,687	23,636	27,586
System 2. Interstate urban					
1. NE	11,215	14,808	18,401	21,991	25,588
2. MA	21,054	28,000	34,945	41,890	48,836
3. SAN	24,695	32,795	40,894	48,993	57,091
4. SAS	6,208	8,240	10,272	12,303	14,335
5. ENC	8,364	11,005	13,646	16,287	18,928
6. WNC	10,299	13,586	16,873	20,160	23,446
7. ESC	12,000	16,053	20,106	24,159	28,212
8. WSC	8,718	11,748	14,778	17,807	20,837
9. M	5,599	7,567	9,534	11,501	13,469
10. P	14,007	18,537	23,067	27,597	32,128
System 3. Primary rural					
1. NE	1,864	2,524	3,183	3,842	4,502
2. MA	1,303	1,790	2,279	2,767	3,255
3. SAN	2,190	2,986	3,779	4,574	5,368
4. SAS	1,145	1,681	2,217	2,752	3,288
5. ENC	1,046	1,418	1,790	2,162	2,535
6. WNC	761	1,061	1,361	1,661	1,961
7. ESC	939	1,353	1,767	2,181	2,596
8. WSC	523	792	1,061	1,330	1,600
9. M	316	464	613	762	911
10. P	2,634	3,578	4,521	5,464	6,407

Table 10-14. -- Dollars of construction cost for structural steel per mile of highway, excess of cost over standard H20-S16 design

Sheet 2 of 2

Census division	18/32	20/35	22/38	24/41	26/44
System 4. Primary urban					
1. NE	4,765	6,581	8,396	10,211	12,027
2. MA	3,945	5,360	6,776	8,191	9,607
3. SAN	6,218	8,358	10,497	12,637	14,777
4. SAS	2,473	3,500	4,527	5,554	6,581
5. ENC	4,569	6,026	7,482	8,938	10,395
6. WNC	910	1,258	1,607	1,955	2,303
7. ESC	1,325	1,909	2,494	3,078	3,662
8. WSC	1,540	2,116	2,691	3,267	3,843
9. M	612	853	1,094	1,335	1,575
10. P	11,555	15,686	19,818	23,949	28,081
System 5. Secondary rural					
1. NE	226	309	392	475	558
2. MA	280	384	488	592	696
3. SAN	280	377	475	572	670
4. SAS	417	585	754	923	1,091
5. ENC	252	340	427	514	601
6. WNC	233	338	444	549	655
7. ESC	776	1,088	1,400	1,712	2,024
8. WSC	214	350	486	621	757
9. M	104	171	237	304	370
10. P	331	464	598	731	864
System 6. Secondary urban					
1. NE	5,544	7,726	9,908	12,090	14,272
2. MA	6,238	8,740	11,242	13,744	16,246
3. SAN	6,415	8,665	10,916	13,166	15,417
4. SAS	7,345	10,239	13,132	16,025	18,918
5. ENC	9,041	12,035	15,029	18,023	21,017
6. WNC	3,587	4,967	6,348	7,728	9,109
7. ESC	9,721	13,838	17,954	22,071	26,187
8. WSC	8,682	11,918	15,154	18,389	21,625
9. M	2,680	3,821	4,962	6,103	7,244
10. P	21,064	28,314	35,563	42,813	50,062

each census division by multiplying the pounds in table 10-13 by the cost in cents per pound as given in table 8-4 for each census division. It will be noted in table 10-13 that additional increments of steel are required for the basic 18/32-kip axle loading, because the critical vehicle used in this design process required some additional steel over the present H20-S16 design normally used in Federal-aid work.

By adding the incremental costs in table 10-14 to the base costs given in table 10-12, the total costs of bridges per mile of highway were obtained for each of the five levels of axle-weight limits. These total costs are given in table 8-10, page 8-28, along with other costs of construction of the complete highway.

D. Cost of Construction of Earthwork and Small Drainage Structures

The only cost of earthwork and small drainage structures that is considered to increase with increased maximum axle-weight limits is that which would result from any additional depth of earthwork excavations necessitated by a greater total depth of pavement structure. Allowance was made for this by added construction cost computed for each highway system and census division on the basis of the computed total depth of the pavement (and shoulder) structure.

The cubic yards of extra excavation per mile were calculated for each of the axle-weight levels above the base condition on the basis that one-half of the mile was cut and the other half was fill. The increment of earthwork cost for the added axle-weight limit was added to the base earthwork costs in table 8-9 to get the total cost given in table 10-28N (page 10-74) and similar ones.

7. COST OF HIGHWAY MAINTENANCE AS RELATED TO MAXIMUM AXLE-WEIGHT LIMITS

The relation between axle-weight limits and the cost of maintaining a highway would vary only on the items of pavement and shoulders and of bridges. The procedure for estimating the cost of these two items of maintenance is discussed below.

A. Pavement Maintenance Cost Attributable to Increases in Maximum Axle-Weight Limits

Accepting the conclusion that the only maintenance operation affected by vehicle axle weight is the patching of pavements, where the surface must be cut through and the narrow strip of shoulder adjacent to the pavement edge must be patched, two further determinations are needed: (1) What is the maintenance cost per mile or per lane-mile of highway for a base condition such as that for the 18/32-kip axle-weight limit and (2) on what basis may this base cost be increased with increases in maximum limits of axle weight.

It was assumed that the annual cost of patching resulting from the effects of axle weight would be 20 percent of the total annual cost of maintaining the pavement and base course and the shoulders, as given in table 8-12. The values in this table are National averages, and to reduce maintenance costs to a census division basis, maintenance-cost indexes based on the wage rate for common labor were used.

The incremental increase in the base cost of maintenance patching as the maximum axle-weight limit is increased was calculated in direct ratio to the increase in pavement depth. For rigid pavement, only the slab depth was used, but for flexible pavements the bituminous concrete depth plus the depth of base was used. The annual cost per mile of 2-lane highway of maintaining the pavement and shoulders for the base condition at the 18/32-kip axle-weight limit is given in table 10-16.

B. Bridge Maintenance Cost Attributable to Increases in Maximum Axle Weights

Painting every six to seven years is the major cost of maintenance of steel bridges. The annual maintenance cost of structures may be assumed to be proportional to the added pounds of steel required for the increased axle-weight limits.

Using a 6- to 7-year frequency and a $15 to $20 cost of painting a ton of steel, the average annual cost of bridge

Table 10-16.--Annual cost per highway mile of patching pavement and shoulders as a result of effects from axle weight applications

Cost in dollars per year per mile for a 2-lane roadway for the 18/32 kip axle level. Costs apply to both rigid and flexible pavements.

Census division	Maintenance cost index 1/	Interstate system 2-lane		Primary system 2-lane		Secondary system 2-lane	
		rural	urban	rural	urban	rural	urban
1. NE	1.023	$286	$443	$224	$338	$ 97	$173
2. MA	1.134	318	491	248	374	108	192
3. SAN	0.804	225	348	176	265	76	136
4. SAS	0.730	204	316	160	241	69	123
5. ENC	1.156	324	501	253	381	110	195
6. WNC	0.972	272	421	213	321	92	164
7. ESC	0.759	212	329	166	250	72	128
8. WSC	0.745	209	323	163	246	71	126
9. M	1.171	328	507	256	386	111	198
10. P	1.479	414	640	324	488	141	250
National 2/	1.000	1,398	2,165	1,094	1,648	477	847
	0.200	280	433	219	330	95	169

1/ Based on wage rate for common labor.

2/ Annual dollars cost is taken as 20 percent of the cost of maintaining surface, base and shoulders given in table 8-12.

maintenance, as it may be affected by vehicle axle-weight limits, was assumed to be $3 per year per ton of steel in excess of the base tonnage.

The maintenance cost of $3 a ton of steel is a National average, which was converted to a census division basis using the maintenance cost index given in table 10-17. The maintenance cost of bridges for the pounds of steel in excess of the standard H20-S16 design is given in table 10-18 for the six highway systems.

8. MOTOR VEHICLE OPERATING COST-- PROCEDURE FOR CALCULATION

The important result of increasing the legal limits on dimensions and weights of motor vehicles would be a reduction in the number of vehicles required to transport a given tonnage of goods over the highway. As the gross weight of trucks increases, their operating cost per vehicle-mile likewise increases but at a slower rate. The number of vehicles required to transport a given tonnage of goods, therefore, decreases with increased gross vehicle weights. Within some range of change, the reduced number of vehicles times their operating cost in cents per mile would result in a lower payload per ton-mile operating cost than would be the case if the total payload were transported in a greater number of vehicles having lower gross weights and lower operating costs per mile.

Table 10-17.--Unit cost per ton of structural steel of repainting steel bridges

Census division	Bridge maintenance cost index 1/	Equivalent annual cost of repainting steel bridges	Equivalent annual cost of repainting steel bridges 1/
		Dollars per ton	Dollars per pound
1. NE	0.995	2.98	0.00149
2. MA	1.087	3.26	.00163
3. SAN	0.678	2.03	.00101
4. SAS	0.772	2.32	.00116
5. ENC	1.108	3.32	.00166
6. WNC	1.052	3.16	.00158
7. ESC	1.121	3.36	.00168
8. WSC	0.776	2.33	.00116
9. M	1.112	3.34	.00167
10. P	1.388	4.16	0.00208
National	1.000	2/ 3.00	0.00150

1/ Based on wage rate of skilled labor.
2/ Based upon a repainting cost of $18 a ton of structural steel and a repainting cycle of 6 years of $3 per year per ton of steel.

Table 10-18. -- Annual highway cost per mile of repainting steel bridges: excess above the standard H20-S16 design.

Sheet 1 of 2

Census division	Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44
1. Interstate rural					
1. NE	$ 58	$ 78	$ 97	$117	$136
2. MA	142	190	238	285	333
3. SAN	135	180	225	269	314
4. SAS	44	60	76	91	107
5. ENC	76	101	127	152	177
6. WNC	44	59	74	89	104
7. ESC	71	94	117	140	163
8. WSC	47	67	86	106	125
9. M	29	40	51	62	72
10. P	85	114	142	171	200
2. Interstate urban					
1. NE	377	498	619	739	860
2. MA	1,261	1,677	2,093	2,509	2,925
3. SAN	483	641	799	958	1,116
4. SAS	376	500	623	746	869
5. ENC	704	926	1,148	1,370	1,592
6. WNC	517	682	850	1,011	1,176
7. ESC	499	668	837	1,005	1,174
8. WSC	355	478	602	725	848
9. M	285	386	486	586	687
10. P	1,026	1,358	1,690	2,022	2,351
3. Primary rural					
1. NE	16	22	28	34	40
2. MA	12	16	20	25	29
3. SAN	13	18	23	27	32
4. SAS	10	14	18	23	27
5. ENC	11	15	19	23	27
6. WNC	6	8	11	13	15
7. ESC	8	12	15	19	23
8. WSC	4	6	8	10	12
9. M	2	4	5	6	7
10. P	23	31	39	47	55

Table 10-18. -- Annual highway cost per mile of repainting steel bridges: excess above the standard H20-S16 design.

Sheet 2 of 2

Census division	Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44
4. Primary urban					
1. NE	$ 42	$ 58	$ 74	$ 90	$106
2. MA	35	46	60	73	85
3. SAN	37	50	63	76	89
4. SAS	20	29	38	46	55
5. ENC	48	63	78	93	109
6. WNC	7	10	13	15	18
7. ESC	11	17	22	27	32
8. WSC	11	15	19	24	28
9. M	5	7	9	11	12
10. P	100	137	171	207	243
5. Secondary rural					
1. NE	2	3	3	4	5
2. MA	2	3	4	5	6
3. SAN	2	2	3	3	4
4. SAS	3	5	6	8	9
5. ENC	3	4	4	5	6
6. WNC	2	3	3	4	5
7. ESC	6	9	12	15	17
8. WSC	2	3	4	4	5
9. M	1	1	2	2	3
10. P	3	4	5	6	7
6. Secondary urban					
1. NE	49	68	87	106	126
2. MA	55	78	100	122	144
3. SAN	38	52	65	78	92
4. SAS	61	85	109	133	157
5. ENC	95	126	157	189	220
6. WNC	28	39	50	60	71
7. ESC	84	120	156	191	227
8. WSC	63	86	110	133	156
9. M	21	30	39	48	57
10. P	182	245	308	370	433

Table 10-19 gives the practical maximum gross vehicle weights for 13 vehicle types for the five levels of maximum axle-weight limits. The steering-axle weights were based upon the 1962 and 1963 weighings of trucks by the State highway departments.

9. CALCULATION OF THE BENEFIT-COST RATIO FOR THE ECONOMY OF AXLE-WEIGHT LIMITS

In the analysis of the economy of increased maximum axle-weight limits, the final comparison is based upon the ratio of the decreased annual cost of motor truck operation with each incremental increase in axle-weight limit (the benefits) to the incremental increase in the equivalent uniform annual highway costs (the costs).

A. Average Daily Traffic

Table 10-22 gives the number of each vehicle class in the total ADT for the primary rural system, census divisions 5 and 6 and axle-weight level. Note that the truck classes from 2D upward are the ones that decrease as the maximum axle-weight limit increases.

B. Computed Depths of Pavement Structure and Construction Cost

The pavement depths and the pavement costs for each of the six highway systems and the ten census divisions were calculated by the computer for both rigid and flexible pavements.

Table 10-19. -Practical maximum gross vehicle weight with a range of maximum axle weights

Sheet 1 of 2

Vehicle and axle	Single/tandem axle weight limit, kips				
	18/32	20/35	22/38	24/41	26/44
2D					
Steering	7.4	8.2	9.0	9.8	10.6
Drive single	18.0	20.0	22.0	24.0	26.0
Total	25.4	28.2	31.0	33.8	36.6
3A. Single unit truck					
Steering axle	9.6	10.2	10.8	11.4	12.0
Drive tandem	32.0	35.0	38.0	41.0	44.0
Total	41.6	45.2	48.8	52.4	56.0
2-S1					
Steering	7.6	8.0	8.3	8.5	8.6
Drive single	18.0	20.0	22.0	24.0	26.0
Semi-single	18.0	20.0	22.0	24.0	26.0
Total	43.6	48.0	52.3	56.5	60.6
2-S2					
Steering	8.4	8.7	9.0	9.3	9.6
Drive single	18.0	20.0	22.0	24.0	26.0
Semi-tandem	32.0	35.0	38.0	41.0	44.0
Total	58.4	63.7	69.0	74.3	79.6
3-S2					
Steering	9.7	10.0	10.3	10.6	10.9
Drive tandem	32.0	35.0	38.0	41.0	44.0
Semi-tandem	32.0	35.0	38.0	41.0	44.0
Total	73.7	80.0	86.3	92.6	98.9
2-2					
Steering	8.6	8.8	9.0	9.2	9.4
Drive single	18.0	20.0	22.0	24.0	26.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Total	62.6	68.8	75.0	81.2	87.4
2-3					
Steering	8.6	8.8	9.0	9.2	9.4
Drive single	18.0	20.0	22.0	24.0	26.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Trailer tandem	32.0	35.0	38.0	41.0	44.0
Total	76.6	83.8	91.0	98.2	105.4
3-2					
Steering	9.8	10.2	10.6	11.0	11.4
Drive tandem	32.0	35.0	38.0	41.0	44.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Total	77.8	85.2	92.6	100.0	107.4

Table 10-19. -Practical maximum gross vehicle weight with a range of maximum axle weights

Sheet 2 of 2

Vehicle and axle	Single/tandem axle weight limit, kips 18/32	20/35	22/38	24/41	26/44
2-S1-2					
Steering	8.7	8.9	9.1	9.3	9.5
Drive single	18.0	20.0	22.0	24.0	26.0
Semi-single	18.0	20.0	22.0	24.0	26.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Total	80.7	88.9	97.1	105.3	113.5
2-S2-2					
Steering	9.3	9.7	10.1	10.5	10.9
Drive single	18.0	20.0	22.0	24.0	26.0
Semi-tandem	32.0	35.0	38.0	41.0	44.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Total	95.3	104.7	114.1	123.5	132.9
2-S2-3					
Steering	9.3	9.7	10.1	10.5	10.9
Drive single	18.0	20.0	22.0	24.0	26.0
Semi-tandem	32.0	35.0	38.0	41.0	44.0
Trailer single	18.0	20.0	22.0	24.0	26.0
Trailer tandem	32.0	35.0	38.0	41.0	44.0
Total	109.3	119.7	130.1	140.5	150.9
3-S2-4					
Steering	10.0	10.3	10.6	10.9	11.2
Drive tandem	32.0	35.0	38.0	41.0	44.0
Semi-tandem	32.0	35.0	38.0	41.0	44.0
Trailer tandem	32.0	35.0	38.0	41.0	44.0
Trailer tandem	32.0	35.0	38.0	41.0	44.0
Total	138.0	150.3	162.6	174.9	187.2
3-4					
Steering	9.8	10.2	10.6	11.0	11.4
Drive tandem	32.0	35.0	38.0	41.0	44.0
Trailer tandem	32.0	35.0	38.0	41.0	44.0
Trailer tandem	32.0	35.0	38.0	41.0	44.0
Total	105.8	115.2	124.6	134.0	143.4

TABLE 10-22.-- NUMBER OF EACH CLASS OF VEHICLE IN THE ADT FOR 1962 AND 1990 FOR EACH CENSUS DIVISION AS USED IN THE ANALYSIS OF THE ECONOMY OF AXLE WEIGHT

SYSTEM 3 — Method 1, with payload increase

SINGLE AXLE WEIGHT LIMIT KIPS	PASS CARS	BUSES	PANEL AND PICKUP	2S	2D	3A	SEMI- 3-AXLE	SEMI- 4-AXLE	SEMI- 5-AXLE	COMB 5-AXLE	2-TLR 5-AXLE	SUB TOTAL	TOTAL
CENSUS DIVISION 5													
1962													
18	2596.0	9.0	143.0	35.0	142.0	22.0	46.0	135.0	85.0	3.0	5.0	438.0	3221.0
20	2596.0	9.0	143.0	35.0	131.9	20.0	43.5	127.5	79.5	2.8	4.7	409.9	3192.9
22	2596.0	9.0	143.0	35.0	122.8	18.3	41.0	121.0	74.5	2.6	4.4	384.6	3167.6
24	2596.0	9.0	143.0	35.0	114.7	17.0	38.5	115.5	70.0	2.4	4.1	362.2	3145.2
26	2596.0	9.0	143.0	35.0	107.6	15.8	36.0	111.0	66.0	2.2	3.8	342.4	3125.4
1990													
18	3211.0	7.0	198.0	49.0	148.0	27.0	40.0	180.0	136.0	4.0	6.0	541.0	4006.0
20	3211.0	7.0	198.0	49.0	137.5	25.0	37.5	170.0	127.2	3.8	5.7	506.7	3971.7
22	3211.0	7.0	198.0	49.0	128.0	23.0	35.0	161.3	119.2	3.6	5.4	475.5	3940.5
24	3211.0	7.0	198.0	49.0	119.6	21.0	32.5	154.0	112.0	3.4	5.1	447.6	3912.6
26	3211.0	7.0	198.0	49.0	112.2	19.0	30.0	148.0	105.6	3.2	4.8	422.8	3887.8
CENSUS DIVISION 6													
1962													
18	1273.0	5.0	95.0	14.0	65.0	15.0	13.0	33.0	50.0	.0	.0	176.0	1563.0
20	1273.0	5.0	95.0	14.0	60.5	14.0	12.3	31.0	46.6	.0	.0	164.3	1551.3
22	1273.0	5.0	95.0	14.0	56.4	13.0	11.6	29.3	43.5	.0	.0	153.8	1540.8
24	1273.0	5.0	95.0	14.0	52.7	12.0	10.9	27.9	41.0	.0	.0	144.5	1531.5
26	1273.0	5.0	95.0	14.0	49.4	11.0	10.2	26.8	39.0	.0	.0	136.4	1523.4
1990													
18	1466.0	4.0	123.0	18.0	63.0	17.0	10.0	41.0	73.0	.0	.0	204.0	1815.0
20	1466.0	4.0	123.0	18.0	58.6	16.0	9.5	38.6	67.9	.0	.0	190.5	1801.5
22	1466.0	4.0	123.0	18.0	54.7	15.0	9.0	36.4	63.6	.0	.0	178.6	1789.6
24	1466.0	4.0	123.0	18.0	51.1	14.0	8.5	34.7	59.8	.0	.0	168.1	1779.1
26	1466.0	4.0	123.0	18.0	47.9	13.0	8.0	33.3	56.9	.0	.0	159.1	1770.1

Table 10-23A is a direct reproduction of the computer printout for the primary rural system.

C. Calculation of the Equivalent
Uniform Annual Highway Cost

Table 10-28N (page 10-74) gives the National averages for highway construction costs and annual highway maintenance costs in the six highway systems as calculated by the procedure described in the preceding sections for Method 1-M. The total construction cost for paving, bridges, and earthwork was reduced to an annual capital cost by multiplying it by the capital recovery factor of 0.087185 assuming a 6-percent annual interest rate and an analysis period of 20 years. This factor reduces the construction costs to an equal annual cost equivalent to an annual depreciation charge plus an interest charge on the undepreciated cost.

D. Calculation of the Equivalent Uniform
Annual Motor Vehicle Operating Cost

The annual motor vehicle operating costs at the five axle-weight levels are also given in table 10-28N. Operating costs are given only for those vehicles (the 2D and upward) which would make some use of the increased axle-weight limits under a change of the law. While passenger buses would make some use of the increase, such use is not considered. The total costs have two components: (1) the operating cost for the first year of the 20-year analysis period (1965) and continued for 20 years, plus

TABLE 10-226 Computer printout on pavement design and pavement construction cost as affected by axle weight maximum limits by highway system and census division.

Analysis method 1-WP-WT-ETB. With 29 percent increase in payload 1962 to 1990 and with the 5-year transition period.

HIGHWAY SYSTEM 2, INTERSTATE URBAN

CENSUS DIV.	EQ AXLE LOAD	NO. LNS	EQ YEAR	TOTAL E18	RIGID PAVEMENT DEPTH PVMT INCHES	RIGID PAVEMENT COST/MILE	COST CHANGE	EQ YEAR	TOTAL E18	FLEXIBLE PAVEMENT DEPTH IN INCHES PVMT	BASE	SB	COST/MILE	COST CHANGE
1. NE	18	4		1301.7	8.19	203758.52			1155.0	3.18	6.36	21.09	176501.60	
							2558.46							1816.95
	20	4	82.9	1523.5	8.41	206316.98		83.2	1312.2	3.23	6.46	21.40	178318.55	
							2373.12							1810.36
	22	4	81.2	1756.6	8.61	208690.10		81.7	1484.7	3.28	6.56	21.70	180128.91	
							2147.78							1731.47
	24	4	79.8	1992.4	8.79	210837.88		80.4	1664.9	3.33	6.66	21.98	181860.38	
							1938.90							1641.70
	26	4	78.7	2227.4	8.95	212776.78		79.4	1849.6	3.37	6.75	22.25	183502.08	
2. MA	18	4		3182.3	9.49	254842.64			2704.9	3.54	7.08	13.25	248805.76	
							2834.54							2978.00
	20	4	83.3	3511.4	9.69	257677.18		83.4	3045.8	3.59	7.19	13.57	251783.76	
							2777.46							2894.72
	22	4	81.8	4077.8	9.88	260454.64		82.0	3411.6	3.64	7.29	13.88	254678.48	
							2626.78							2717.94
	24	4	80.6	4564.4	10.07	263081.42		80.8	3738.6	3.69	7.39	14.18	257396.42	
							2458.06							2528.68
	26	4	79.5	5063.0	10.24	265539.48		79.8	4171.0	3.74	7.48	14.45	259925.10	
3. SAN	18	4		1999.8	9.02	227520.60			1672.6	3.79	7.59	14.78	248079.06	
							2696.60							3827.24
	20	4	83.2	2286.3	9.22	230217.20		83.1	1922.1	3.86	7.72	15.18	251906.30	
							2487.66							3395.72
	22	4	81.7	2580.0	9.40	232704.86		81.6	2170.8	3.92	7.84	15.54	255302.02	
							2309.66							3121.12
	24	4	80.5	2880.3	9.57	235014.52		80.4	2424.4	3.97	7.95	15.87	258423.14	
							2076.52							2783.08
	26	4	79.6	3174.5	9.73	237091.04		79.5	2672.9	4.02	8.05	16.16	261206.22	
4. SAS	18	4		1097.3	7.83	211981.06			901.8	2.78	5.56	8.68	128637.91	
							2835.70							1596.28
	20	4	83.0	1282.0	8.03	214816.76		83.1	1043.9	2.83	5.66	8.98	130234.19	
							2671.72							1491.16
	22	4	81.3	1478.9	8.22	217488.48		81.5	1193.6	2.87	5.75	9.27	131725.35	
							2524.48							1398.75
	24	4	80.0	1687.2	8.40	220012.96		80.2	1350.2	2.92	5.84	9.53	133124.10	
							2318.14							1276.80
	26	4	78.9	1899.2	8.56	222331.10		79.2	1508.1	2.96	5.92	9.78	134400.90	
5. ENC	18	4		2125.4	9.11	221510.42			1684.7	3.80	7.60	14.80	194220.12	
							2723.46							2743.86
	20	4	83.1	2445.2	9.32	224233.88		83.2	1919.5	3.86	7.72	15.18	196963.98	
							2505.72							2532.57
	22	4	81.7	2773.9	9.51	226739.60		81.8	2161.8	3.92	7.64	15.53	199496.55	
							2321.90							2355.85
	24	4	80.4	3110.5	9.69	229061.50		80.6	2411.6	3.97	7.95	15.85	201852.40	
							2068.62							2108.46
	26	4	79.5	3438.3	9.85	231130.12		79.7	2657.1	4.02	8.04	16.14	203960.86	
6. WNC	18	4		937.5	7.76	220647.62			714.7	2.99	5.99	9.99	156143.99	
							2528.02							1851.87
	20	4	83.2	1070.5	7.93	223175.64		83.3	807.8	3.04	6.09	10.27	157995.86	
							2423.80							1746.05
	22	4	81.7	1212.3	8.10	225599.44		82.0	904.5	3.08	6.17	10.52	159741.91	
							2322.10							1649.48
	24	4	80.5	1362.4	8.26	227921.54		80.8	1004.3	3.12	6.25	10.76	161391.39	
							2126.46							1488.05
	26	4	79.5	1513.0	8.40	230048.00		79.9	1101.9	3.16	6.32	10.98	162879.44	
7. ESC	18	4		2526.1	9.37	246214.26			2146.2	3.91	7.83	15.50	225410.52	
							2538.58							2664.80
	20	4	83.4	2837.2	9.55	248752.84		83.6	2383.6	3.97	7.94	15.82	228075.32	
							2473.18							2515.16
	22	4	82.1	3170.3	9.72	251226.02		82.4	2629.3	4.01	8.03	16.11	230590.48	
							2399.90							2380.66
	24	4	80.9	3524.0	9.89	253625.92		81.3	2883.1	4.06	8.13	16.39	232971.14	
							2218.28							2147.62
	26	4	80.0	3879.4	10.05	255844.20		80.5	3131.2	4.10	8.21	16.65	235118.76	
8. WSC	18	4		1375.6	8.48	190529.51			1063.5	3.59	7.18	13.54	174393.90	
							2232.02							2515.46
	20	4	83.1	1585.6	8.68	192761.53		83.2	1212.7	3.64	7.29	13.89	176909.36	
							2057.50							2364.91
	22	4	81.6	1802.2	8.86	194819.03		81.8	1369.0	3.70	7.40	14.22	179274.27	
							1909.89							2228.18
	24	4	80.4	2024.7	9.03	196728.92		80.6	1532.1	3.75	7.51	14.54	181502.45	
							1705.31							2013.47
	26	4	79.4	2242.1	9.19	198434.23		79.6	1693.9	3.80	7.60	14.82	183515.92	
9. M	18	4		1887.2	8.44	169989.74			1396.8	2.55	5.10	7.30	99956.48	
							2068.83							1031.52
	20	4	83.3	2155.5	8.62	172058.57		83.5	1566.5	2.58	5.17	7.52	100988.00	
							1907.04							993.13
	22	4	81.9	2430.3	8.79	173965.61		82.2	1746.1	2.62	5.24	7.73	101981.13	
							1769.98							955.62
	24	4	80.8	2710.7	8.95	175735.59		81.1	1935.0	2.65	5.31	7.94	102936.75	
							1586.71							883.78
	26	4	79.9	2984.5	9.10	177322.30		80.2	2124.7	2.68	5.37	8.13	103820.53	
10. P	18	4		3591.3	9.51	201896.42			2843.8	3.21	6.42	11.27	160893.01	
							2026.18							2483.79
	20	4	83.5	4020.2	9.68	203922.60		83.2	3260.2	3.26	6.53	11.61	163376.80	
							1939.28							2286.58
	22	4	82.3	4469.7	9.85	205861.88		81.8	3685.5	3.32	6.64	11.92	165563.38	
							1856.86							2121.10
	24	4	81.2	4938.6	10.02	207718.74		80.7	4118.8	3.36	6.73	12.21	167784.48	
							1709.86							1907.90
	26	4	80.3	5406.0	10.17	209428.60		79.8	4543.0	3.41	6.82	12.47	169692.38	

(2) the equivalent uniform annual cost for the increased ADT over the 20-year period. The increase in ADT was calculated as a uniform (gradient) increase for each of the 20 years. This gradient expressed in dollars per year was reduced to an equivalent uniform annual amount by multiplying the yearly uniform increase in operating cost by the gradient factor of 8.605 for a 6-percent interest rate and a period of 20 years. This procedure discounts the future increasing motor vehicle operating costs to an equivalent uniform annual cost.

The calculation of the motor vehicle operating cost in table 10-28N was based upon the same transition period (1, 2, 3, or 5 years beginning January 1, 1965) as was used in the calculation of the equivalent 18-kip axle applications. The equivalent decremental change in motor vehicle operating cost was obtained by successive subtraction of the operating costs at each axle-weight level.

E. The Benefit-Cost Ratios

The last line of table 10-28N gives the final ratios of the equivalent uniform annual incremental motor vehicle benefits to the equivalent uniform annual incremental highway costs. These benefit-cost ratios are shown for each level of upward change in maximum axle-weight limits, beginning with the increment between the 18/32-kip and 20/35-kip axle-weight levels.

10. CONSIDERATIONS RELATIVE TO THE AASHO INTERIM PAVEMENT DESIGN FORMULAS

In the studies of the economy of the maximum axle-weight limits using Methods 1, 2, and 3, the pavement designs were made by applying without modification the AASHO Interim Guides and the design depths as calculated. The following arrays give the rigid pavement designs for Method 1 for each highway system, arranged from high to low by slab depth for the ten census divisions.

These depths, with the possible exception of the top few for Interstate systems 1 and 2, are materially less than are being constructed by the States. It was concluded that the AASHO design formula for rigid pavements is not in agreement with practice at low traffic volumes, actually low numbers of E 18-kip axle applications. The explanation offered is that the AASHO Road Test did not cover sufficient calendar time to permit time, weathering, and other environmental factors to contribute their combined effects. Therefore, it is to be expected that good design practice under certain conditions would call for increasing the slab depth from that indicated by the AASHO design formula. Further, the applications herein of the AASHO design formula may have extrapolated the formula below its reliable range.

The question is raised, logically, as to whether the final benefit-cost ratios arrived at in Method 1 would be

METHOD 1--RIGID PAVEMENT
Depths of pavement slab, inches

System 1	System 2	System 3	System 4	System 5	System 6
9.25	9.51	7.10	8.37	5.17	6.57
9.24	9.49	7.06	7.57	5.17	6.11
9.15	9.37	6.97	7.38	5.17	6.05
9.04	9.11	6.95	7.26	5.04	5.76
8.96	9.02	6.94	7.16	5.01	5.56
8.16	8.48	6.69	7.16	5.01	5.50
7.81	8.44	6.49	7.13	4.95	5.48
7.81	8.19	6.30	6.69	4.88	5.43
7.58	7.83	5.99	6.58	4.76	5.29
7.21	7.76	5.51	6.49	4.56	4.75

materially greater or smaller if some minimum rigid pavement depth were imposed so that the analysis of economy of axle-weight limits was made to start at the pavement design now generally accepted as adequate under existing axle-weight maximum limits. To answer this question, Method 1 was repeated as Method 1-M, in which minimum limits of pavement depths for both rigid and flexible pavements were used.

11. METHOD 1-M--ECONOMY OF AXLE-WEIGHT LIMIT WHEN USING A MINIMUM DEPTH OF PAVEMENT

By reference to summaries and spot information on pavement design, State by State, found in the Structures and Applied Mechanics Research Division, table 10-26 was prepared, giving the general nominal thickness of rigid pavement slab and of the flexible bituminous surfacing most frequently

Table 10-26.--Minimum pavement depth most frequently used by the States in each census division for each of six highway systems

Census division	1. ISR	2. ISU	Highway system				5. SR	6. SU
			3. PR		4. PU			
	4-lane	4-lane	4-ln	2-ln	4-ln	2-ln	2-lane	2-lane
	Inches of design depth for rigid slab							
1. NE	9.0	9.0	9.0	--	9.0	--	8.0	8.0
2. MA	9.0	9.0	9.0	--	9.0	--	8.0	8.0
3. SAN	9.0	9.0	9.0	--	9.0	--	8.0	8.0
4. SAS	9.0	9.0	9.0	--	9.0	--	8.0	8.0
5. ENC	10.0	10.0	10.0	--	10.0	--	8.0	8.0
6. WNC	9.0	9.0	--	9.0	--	9.0	8.0	8.0
7. ESC	10.0	10.0	--	10.0	--	10.0	8.0	8.0
8. WSC	9.0	9.0	--	9.0	--	9.0	8.0	8.0
9. M	8.0	8.0	--	8.0	--	8.0	8.0	8.0
10. P	9.0	9.0	9.0	--	9.0	--	8.0	8.0
	Inches of design depth for flexible surface course							
1. NE	3.50	3.75	3.25	--	3.25	--	3.00	3.00
2. MA	3.50	3.75	3.25	--	3.25	--	3.00	3.00
3. SAN	3.75	4.00	3.25	--	3.25	--	3.00	3.00
4. SAS	3.50	3.50	3.50	--	3.50	--	3.00	3.00
5. ENC	3.50	4.00	3.25	--	3.25	--	3.00	3.00
6. WNC	3.50	3.75	--	3.25	--	3.25	3.00	3.00
7. ESC	3.50	4.00	--	3.25	--	3.25	3.00	3.00
8. WSC	3.50	4.00	--	3.25	--	3.25	3.00	3.00
9. M	3.00	3.00	--	2.75	--	2.75	2.50	2.50
10. P	3.00	3.50	2.75	--	2.75	--	2.50	2 50

specified by the States in each of the ten census divisions for each of the six highway systems. The number of lanes indicated corresponds to those used in this research on the desirable dimensions and weights of motor vehicles.

Because Method 1-M was designed to be a direct comparison with Method 1, in which a minimum depth was not used (except for the 2 inches for flexible pavement), recourse was had to the relationship in Method 1 of E 18-kip axles to design pavement depth. Because the pavement depth depends upon the number of E 18-kip axle applications and upon soil conditions rather than upon axle-weight limits, it was possible to plot a series of curves similar to figures 10-5 and 10-6 from which to read the number of daily E 18-kip axle applications required to produce the predetermined minimum surface depth in inches of design pavement.

From the series of curves of which figures 10-5 and 10-6 are examples, the depth E-18 relationship was read for all minimum depths, as shown in table 10-27.

The basic difference between Methods 1 and 1-M is simply that of the starting base condition. For Method 1 the base conditions is the daily E 18-kip axle applications from the truck weight data for 1962 and the projected traffic to 1990 for the legal axle weights in 1962. For Method 1-M the base condition is the daily E 18-kip axle applications corresponding to the minimum design depth. Therefore, for

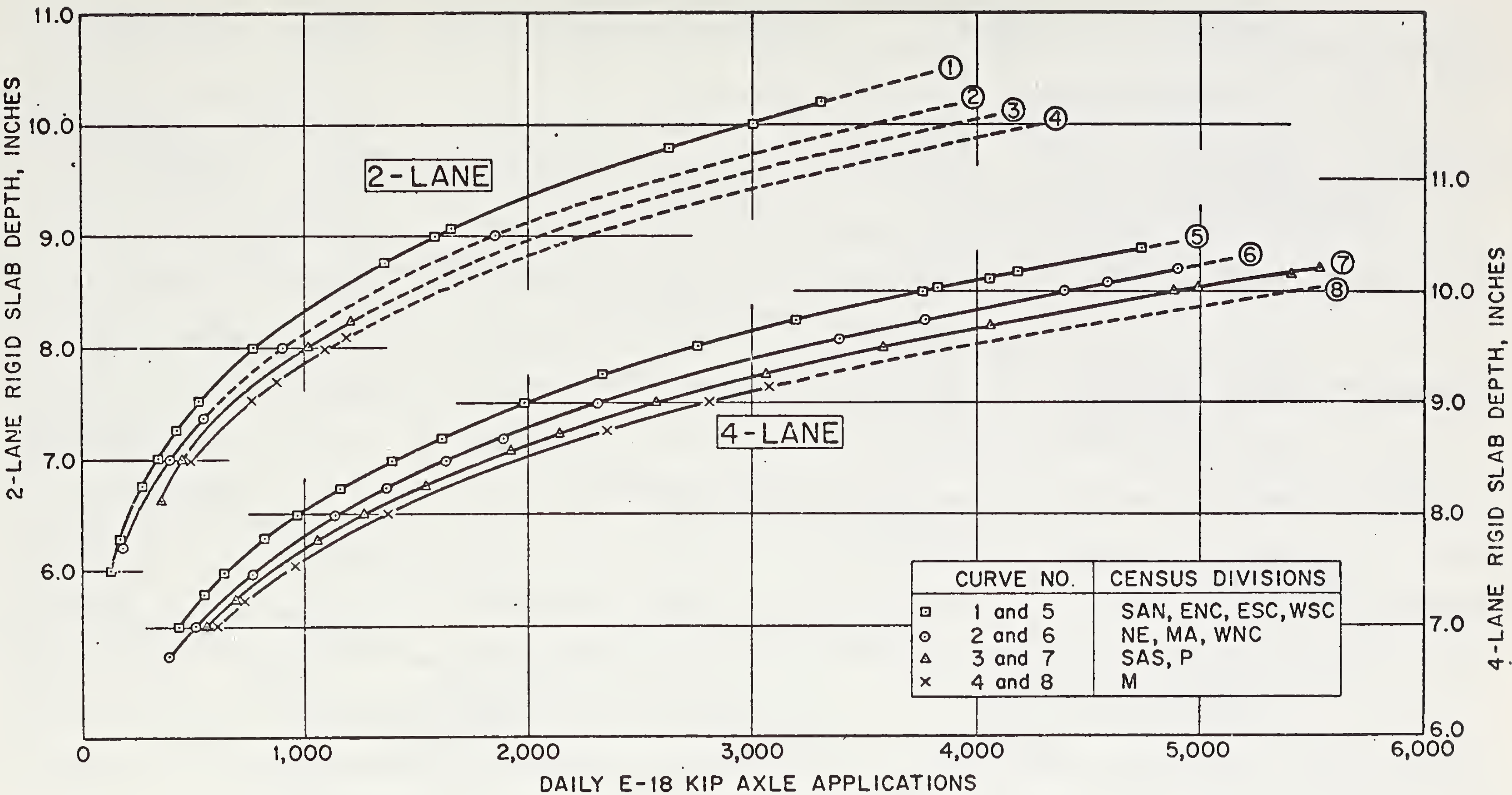


FIGURE 10-5. DESIGN RIGID PAVEMENT SLAB DEPTH RELATED TO DAILY E-18 KIP AXLE APPLICATIONS RESULTING FROM METHODS 1, 2, AND 3 PLOTTED FOR USE WITH METHOD I-M

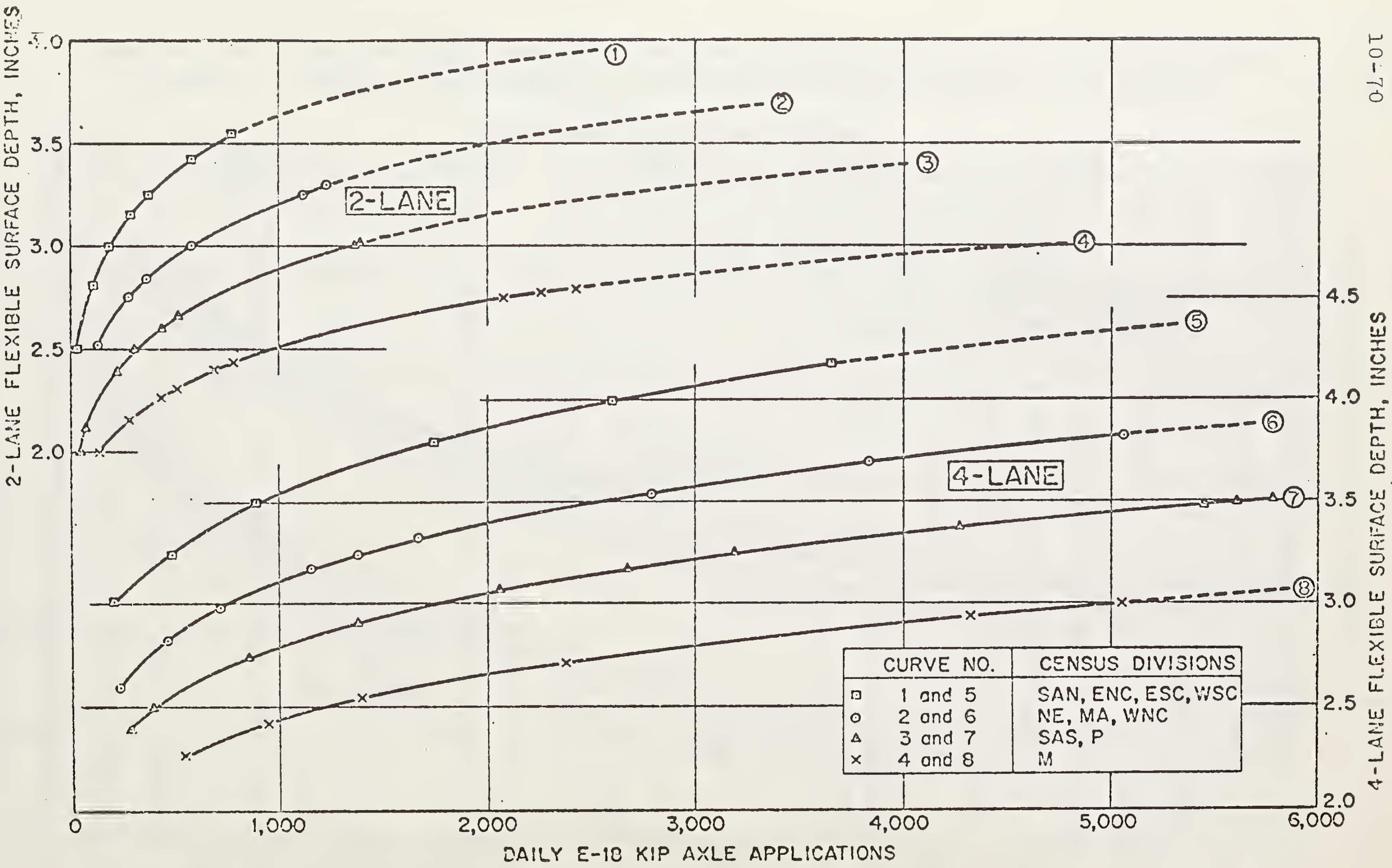


FIGURE 10-6. DESIGN DEPTH OF FLEXIBLE PAVEMENT SURFACE COURSE RELATED TO DAILY E-18 KIP AXLE APPLICATIONS RESULTING FROM METHODS 1, 2, AND 3 PLOTTED FOR USE WITH METHOD I-M

Table 10-27.--Daily E 18 kip axle applications corresponding to minimum design depth of rigid and flexible pavement surfaces, for each census division.

Census division	4-Lane rigid pavement				2-Lane rigid pavement			
	Pavement slab depth, inches				Pavement slab depth, inches			
	7	8	9	10	7	8	9	10
1. New England	499.5	1136.8	2308.0	4388.6	399.4	900.0	1846.4	3510.9
2. Middle Atlantic	499.5	1136.8	2308.0	4388.6	399.4	900.0	1846.4	3510.9
3. South Atlantic North	427.5	963.0	1982.7	3757.4	342.0	773.6	1583.3	3000.0
4. South Atlantic South	558.0	1254.9	2569.6	4877.2	443.5	1003.9	2055.7	3901.8
5. East North Central	427.5	963.0	1982.7	3757.4	342.0	773.6	1583.3	3000.0
6. West North Central	499.5	1136.8	2308.0	4388.6	399.4	900.0	1846.4	3510.9
7. East South Central	427.5	963.0	1982.7	3757.4	342.0	773.6	1583.3	3000.0
8. West South Central	427.5	963.0	1982.7	3757.4	342.0	773.6	1583.3	3000.0
9. Mountain	603.1	1366.5	2805.8	5340.0	489.2	1093.3	2244.6	4272.0
10. Pacific	558.0	1254.9	2569.6	4877.2	443.5	1003.9	2055.7	3901.8

	4-Lane flexible pavement							2-Lane flexible pavement				
	Bituminous surface course, depth, inches							Bituminous surface course, depth, inches				
	2.50	2.75	3.00	3.25	3.50	3.75	4.00	2.50	2.75	3.00	3.25	3.50
1. New England	157.3	353.4	727.6	1385.5	2475.8	4300.0	---	125.8	286.0	582.1	1108.4	1980.6
2. Middle Atlantic	157.3	353.4	727.6	1385.5	2475.8	4300.0	---	125.8	286.0	582.1	1108.4	1980.6

Table 10-27.--Daily E 18 kip axle applications corresponding to minimum design depth of rigid and flexible pavement surfaces, for each census division.

Sheet 2 of 2

Census division	4-Lane flexible pavement							2-Lane flexible pavement				
	Bituminous surface course, depth, inches							Bituminous surface course, depth, inches				
	2.50	2.75	3.00	3.25	3.50	3.75	4.00	2.50	2.75	3.00	3.25	3.50
3. South Atlantic North	50.0	114.4	241.8	479.4	874.4	1535.1	2567.2	39.5	91.5	194.4	376.4	699.5
4. South Atlantic South	379.5	840.5	1683.4	3180.1	5609.3	---	---	303.8	672.4	1346.7	2544.1	4487.4
5. East North Central	50.0	114.4	241.8	479.4	874.4	1535.1	2567.2	39.5	91.5	194.4	376.4	699.5
6. West North Central	157.3	353.4	727.6	1385.5	2475.8	4300.0	---	125.8	286.0	582.1	1108.4	1980.6
7. East South Central	50.0	114.4	241.8	479.4	874.4	1535.1	2567.2	39.5	91.5	194.4	376.4	699.5
8. West South Central	50.0	114.4	241.8	479.4	874.4	1535.1	2567.2	39.5	91.5	194.4	376.4	699.5
9. Mountain	1214.7	2600.0	4320.0	---	---	---	---	971.8	2080.0			
10. Pacific	379.5	840.5	1683.4	3180.1	5609.3	---	---	303.8	672.4	1346.7	2544.1	4487.4

higher axle-weight limits than prevailed at the base condition in 1962, the increase in E 18-kip axle applications would be the same for both Methods 1 and 1-M. Consequently, the design E 18-kip axle applications for the axle-weight limits above the base limits were found for Method 1-M by adding to the base E 18's the same increases calculated for Method 1. The one difference in the resulting designs is simply the starting level--either pavement depth or its corresponding E 18-kip axle applications.

Table 10-27 gives the final E 18-kip daily axle application used as computer input for the base condition for the minimum pavement depths for both rigid and flexible pavements. The computer printed out the pavement designs and the pavement costs for Method 1-M in the same form as those obtained for Method 1. These results are shown on a national basis in table 10-28N. Since Method 1-M assumed the same truck fleet and loads as for Method 1, the truck operating costs were identical for the two methods.

The final highway costs were calculated using exactly the same procedure as followed for Method 1. The pavement costs were higher where the base pavement depth was greater, because of the higher minimum depth, but the increase in depth with increase in axle-weight limits was at a slower rate.

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Table 10-28N.- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984-- National average

Highway System 1. IR Method of Analysis 1-M with transition Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	222,016	223,394	225,251	227,574	229,608	186,899	188,717	190,972	193,590	195,893
b. Bridge structures	200,634	202,212	204,347	207,648	210,948	200,634	202,212	204,347	207,648	210,948
c. Earthwork and drainage	190,465	190,505	190,561	190,641	190,709	190,465	190,591	190,757	190,977	191,173
d. Total construction cost	613,115	616,111	620,159	625,863	631,265	577,998	581,520	586,076	592,215	598,014
2. Equivalent uniform annual capital cost *	53,454	53,716	54,069	54,566	55,037	50,393	50,700	51,076	51,632	52,138
3. Incremental annual cost										
a. Capital cost	—	262	353	477	471	—	307	396	536	506
b. Maintenance cost of pavement and shoulders	—	7	9	11	10	—	6	8	9	8
c. Maintenance cost of structures	—	12	18	25	25	—	12	18	25	25
d. Total equivalent uniform annual highway cost	—	281	380	533	506	—	325	422	570	531
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	232,044	228,713	224,003	218,657	215,181	232,044	228,713	224,003	218,657	215,181
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	3,331	4,710	5,346	3,476	—	3,331	4,710	5,346	3,476
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	11.9	12.4	10.0	6.9	—	10.2	11.2	9.4	6.4

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 10-98U.- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 2. IU

Method of Analysis 1-M with transition

Census Division All

Cost item	Rigid Pavement					Flexible Pavement				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	222,792	223,852	225,279	227,088	228,761	196,957	197,728	198,779	200,113	201,361
b. Bridge structures	1,294,314	1,296,265	1,299,229	1,303,246	1,307,264	1,294,314	1,296,265	1,299,229	1,303,246	1,307,264
c. Earthwork and drainage	492,872	492,902	492,944	493,006	493,063	492,871	492,928	493,008	493,122	493,229
d. Total construction cost	2,009,978	2,013,019	2,017,452	2,023,340	2,029,088	1,984,142	1,986,921	1,991,016	1,996,481	2,001,854
2. Equivalent uniform annual capital cost *	175,240	175,505	175,892	176,405	176,906	172,987	173,230	173,587	174,063	174,532
3. Incremental annual cost										
a. Capital cost	—	265	387	513	501	—	243	357	476	469
b. Maintenance cost of pavement and shoulders	—	9	11	13	12	—	4	5	7	6
c. Maintenance cost of structures	—	111	139	193	193	—	111	139	193	193
d. Total equivalent uniform annual highway cost	—	385	537	719	706	—	358	501	676	668
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	368,086	357,380	346,460	332,350	323,250	368,086	357,380	346,460	332,350	323,250
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	10,706	10,920	14,110	9,100	—	10,706	10,920	14,110	9,100
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	27.8	20.3	19.6	12.9	—	29.9	21.8	20.9	13.6

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 10-28M.- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 3. PR — Method of Analysis 1-M with transition — Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	180,568	180,808	181,212	181,775	182,301	143,781	144,424	145,456	146,656	147,757
b. Bridge structures	31,194	31,439	31,816	32,308	32,801	31,194	31,438	31,816	32,308	32,801
c. Earthwork and drainage	86,710	86,717	86,730	86,751	86,769	86,710	86,755	86,831	86,929	87,020
d. Total construction cost	298,472	298,964	299,758	300,834	301,871	261,685	262,617	264,103	265,893	267,578
2. Equivalent uniform annual capital cost *	26,022	26,065	26,134	26,228	26,319	22,815	22,896	23,026	23,182	23,329
3. Incremental annual cost										
a. Capital cost	—	43	69	94	91	—	81	130	156	147
b. Maintenance cost of pavement and shoulders	—	1	1	2	2	—	2	3	3	3
c. Maintenance cost of structures	—	2	3	4	4	—	2	3	4	4
d. Total equivalent uniform annual highway cost	—	46	73	100	97	—	85	136	163	154
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	56,018	54,860	53,425	51,892	50,992	56,018	54,860	53,425	51,892	50,992
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	1,158	1,435	1,533	900	—	1,158	1,435	1,533	900
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	25.2	19.7	15.3	9.3	—	13.6	10.6	9.4	5.8

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 10-28 U.- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 --National average

Highway System 4. PU   Method of Analysis 1-M with transition   Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	180,567	181,015	181,634	182,420	183,153	145,413	146,239	147,335	148,553	149,645
b. Bridge structures	119,813	120,547	121,597	122,970	124,344	119,813	120,547	121,597	122,970	124,344
c. Earthwork and drainage	173,963	173,978	173,999	174,027	174,054	173,963	174,025	174,106	174,204	174,277
d. Total construction cost	474,343	475,540	477,230	479,417	481,551	439,187	440,811	443,038	445,727	448,236
2. Equivalent uniform annual capital cost *	41,356	41,460	41,607	41,778	41,984	38,291	38,432	38,626	38,861	39,083
3. Incremental annual cost										
a. Capital cost	–	104	147	191	186	–	141	194	235	222
b. Maintenance cost of pavement and shoulders	–	3	4	5	4	–	5	5	5	5
c. Maintenance cost of structures	–	7	9	12	12	–	7	9	12	12
d. Total equivalent uniform annual highway cost	–	114	160	208	202	–	153	208	252	239
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	134,610	128,190	121,647	115,221	112,063	134,610	128,190	121,647	115,221	112,063
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	6,420	6,543	6,426	3,158	–	6,420	6,543	6,426	3,158
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	56.3	40.9	30.9	15.6	–	42.0	31.5	25.5	13.2

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 10-28N- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 5. SR   Method of Analysis 1-M with transition   Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	104,044	104,095	104,157	104,241	104,324	82,197	82,290	82,416	82,571	82,730
b. Bridge structures	9,244	9,329	9,439	9,568	9,698	9,244	9,328	9,439	9,568	9,698
c. Earthwork and drainage	34,247	34,251	34,253	34,255	34,258	34,250	34,255	34,266	34,278	34,290
d. Total construction cost	147,537	147,675	147,849	148,064	148,280	125,691	125,873	126,121	126,417	126,718
2. Equivalent uniform annual capital cost *	12,863	12,875	12,890	12,909	12,928	10,958	10,974	10,996	11,022	11,048
3. Incremental annual cost										
a. Capital cost	—	12	15	19	19	—	16	22	26	26
b. Maintenance cost of pavement and shoulders	—	0	0	0	0	—	0	0	0	0
c. Maintenance cost of structures	—	1	1	1	1	—	1	1	1	1
d. Total equivalent uniform annual highway cost	—	13	16	20	20	—	17	23	27	27
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	10,068	9,777	9,451	9,048	8,816	10,068	9,777	9,451	9,048	8,816
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	291	326	403	232	—	291	326	403	232
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	22.4	20.4	20.2	11.6	—	17.1	14.2	14.9	8.6

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 10-28 N.- Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 6. SU Method of Analysis 1-M with transition Census Division All

Cost item	Rigid Pavement					Flexible Pavement				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	104,044	104,164	104,338	104,548	104,752	82,197	82,427	82,784	83,185	83,571
b. Bridge structures	40,814	42,826	45,352	48,346	51,341	40,814	42,826	45,352	48,346	51,341
c. Earthwork and drainage	49,073	49,052	49,087	49,095	49,102	49,073	49,096	49,125	49,159	49,191
d. Total construction cost	193,936	196,072	198,777	201,989	205,195	172,087	174,349	177,261	180,690	184,103
2. Equivalent uniform annual capital cost *	16,708	17,095	17,330	17,610	17,870	15,004	15,201	15,454	15,753	16,050
3. Incremental annual cost										
a. Capital cost	—	187	235	280	280	—	197	253	299	297
b. Maintenance cost of pavement and shoulders	-	0	1	1	1	-	1	1	1	1
c. Maintenance cost of structures		17	21	25	25	—	17	21	25	25
d. Total equivalent uniform annual highway cost	-	204	257	306	306	—	215	275	325	323
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	29,091	28,301	27,344	26,202	25,521	29,091	28,301	27,344	26,202	25,521
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	790	957	1,142	681	—	790	957	1,142	681
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	3.9	3.7	3.7	2.2	—	3.7	3.5	3.5	2.1

* Calculated at 6 percent interest rate per annum and 20 years.

12. METHOD 2--EXTRAPOLATION BY PRACTICAL GROSS WEIGHT RELATIONSHIPS

By Method 1 for the analysis of the economy of maximum axle-weight limits, the axle-weight distribution for each vehicle class as found in the 1962 truck weight study was transferred from those States having highest limits to those States having lower limits. These axle-weight distributions were extrapolated to get distributions for the axle-weight levels of 22/41 and 26/44 kips. Method 2 uses a more direct approach, but it is also based on the 1962 truck weight study.

A. Payload Weight vs. Practical Maximum Gross Vehicle Weight

For each of 46 States and each class of vehicle, the average payload in pounds carried by all vehicles weighed in 1962 (including the empty vehicles) was plotted against the practical maximum gross weight limit as calculated from the legal maximum axle weight, making proper allowance for the steering axle. See table 10-19 (page 10-59) for these practical maximum gross vehicle weights.

Figure 10-9 gives the final set of these curves for each vehicle class. The curves are extrapolated to cover the practical maximum gross vehicle weight for axle-weight limits up to 26/44 kips. By the application of these payload-gross-weight curves, the number of vehicles necessary to carry the same total tons of payload as carried in 1962, by class of vehicle, was readily computed.

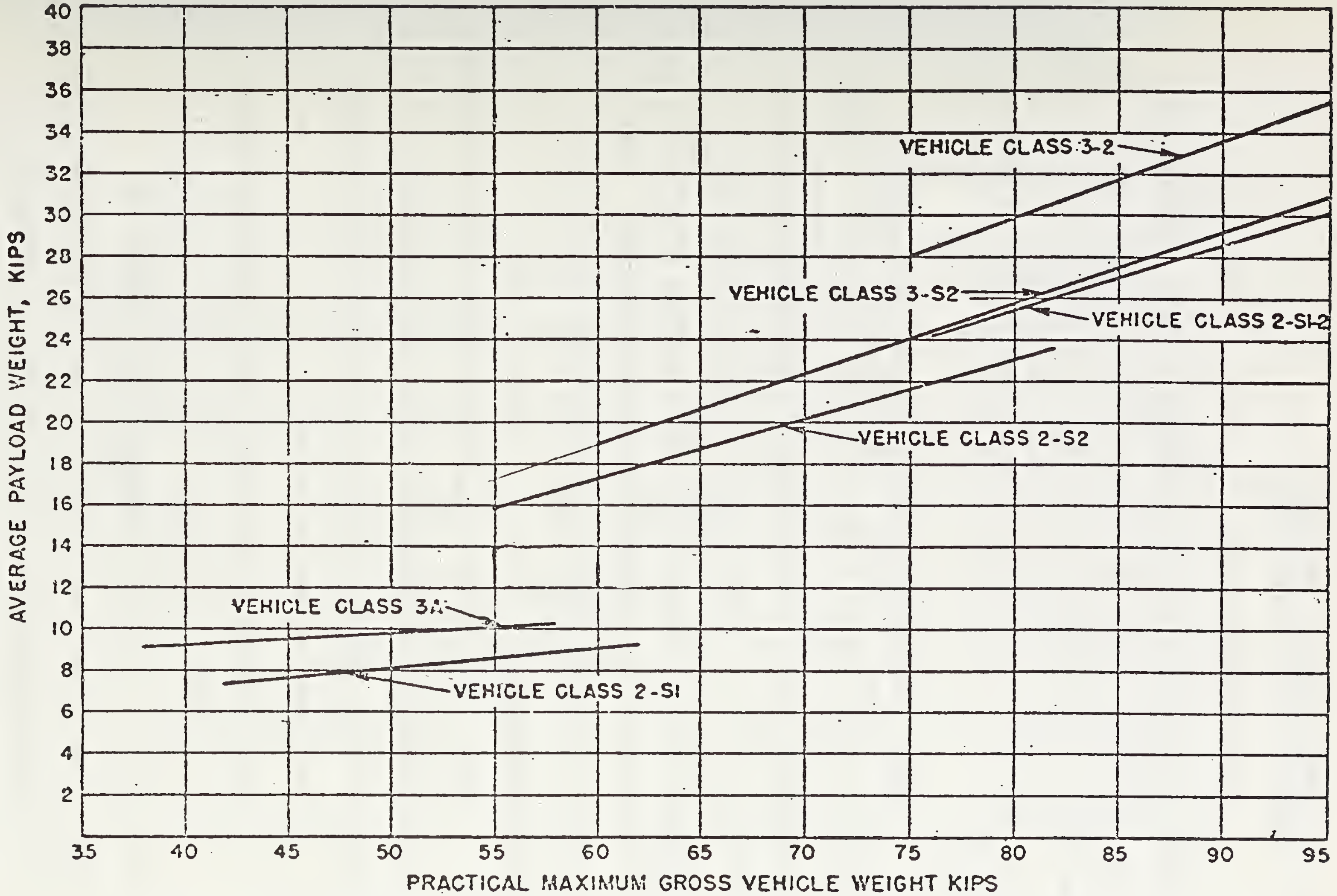

FIGURE 10-9. AVERAGE WEIGHT OF PAYLOAD PER VEHICLE WEIGHED IN THE 1962 TRUCK WEIGHT STUDY FOR EACH VEHICLE CLASS AS RELATED TO PRACTICAL MAXIMUM GROSS VEHICLE WEIGHT FOR THE PRIMARY RURAL HIGHWAY SYSTEM

B. E 18-Kip Axles vs. Practical Maximum Gross Vehicle Weight

The foregoing procedure resulted in the estimate of the number of vehicles (or trips) required to haul the same total tons of payload at the five levels of axle-weight limits. The next step was to estimate the number of E 18-kip axles resulting from the number of vehicles of each class at each axle-weight level.

Again, the State-by-State variation in the maximum practical gross vehicle weight limit was used as the control. The E 18-kip axles were calculated for each vehicle class in each State from the axle-weight distribution found in the 1962 truck weight study. These E 18-kip axles per vehicle were plotted for each vehicle class and each State. Final curves are given in figures 10-12 and 10-13 for rigid and flexible pavements.

The average payload weight per vehicle for each vehicle class for 1990 was increased 29 percent over that shown in figure 10-7 for 1962, but the practical maximum gross weight was held the same in 1990 as in 1962.

The E 18-kip axles per vehicle were likewise increased in 1990 over 1962 to correspond to the payload increase, because such an increase in payload would increase the average gross weight per vehicle and the weight distribution of the load-carrying axles. The increase was estimated by distributing the increased payload weight proportionally

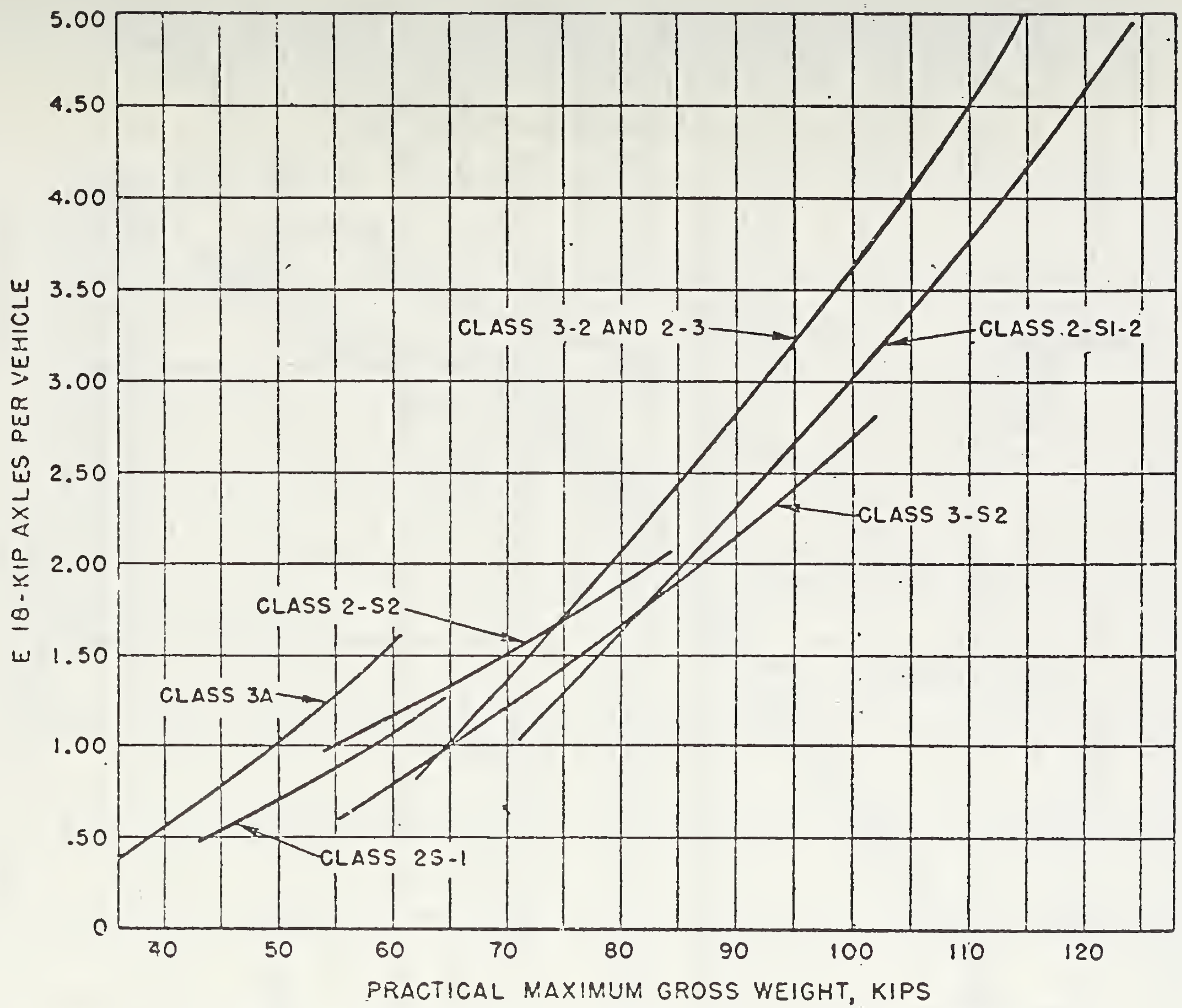

FIGURE 10-12. EQUIVALENT 18-KIP AXLES FOR 8-INCH RIGID PAVEMENT FOR THE SIX VEHICLE CLASSES AND THE 1962 TRUCK WEIGHT STUDY AS RELATED TO PRACTICAL MAXIMUM VEHICLE GROSS WEIGHT.

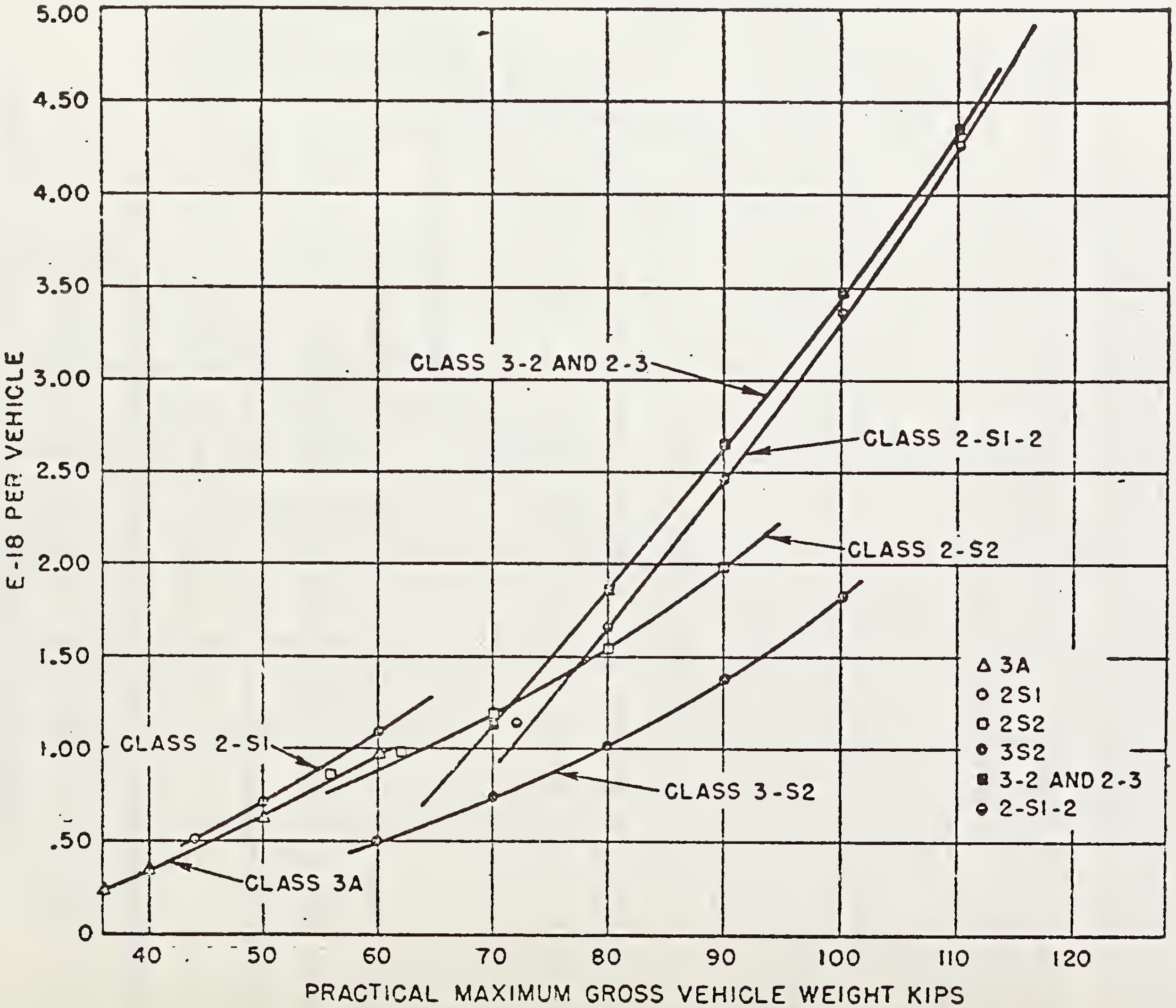

FIGURE 10-13. EQUIVALENT 18-KIP AXLES FOR FLEXIBLE PAVEMENT (SN=3) FOR THE SIX VEHICLE CLASSES AND THE 1962 TRUCK WEIGHT STUDY AS RELATED TO PRACTICAL MAXIMUM VEHICLE GROSS WEIGHT

equally to the load-carrying axles. The appropriate E 18-kip equivalence factor was then applied.

The 1990 practical maximum gross vehicle weight was held to the number of pounds used for 1962 for the respective maximum axle-weight limits. Since the practical maximum gross vehicle weight is a function of maximum legal axle weight, it is unaffected by transport practice. It is assumed, however, that any specific maximum legal gross weight would be equal to the sum of the axle-weight limits.

C. Results of Method 2

Method 2 was developed with and without the transition period, but the tables of results here given are for only the analysis with the transition period.

The results of Method 2 are not presented in detail because the results of Method 1-M are superior for the purposes of this study. The Method 2 results are close enough to those of Method 1 and 1-M to prove the reliability of these other methods--the basic objective of Method 2. In table 10-37 (pages 10-98 to 10-104) some results of Method 2 are given.

13. METHOD 3--REPEAT OF METHOD 2, BUT OMITTING THE 29-PERCENT INCREASE IN PAYLOAD PER VEHICLE 1962 TO 1990

Both Methods 1 and 2 for determining the economy of axle-weight maximum limits included the effects of a 29-percent increase in average payload per vehicle from 1962 to 1990.

Including this increase in payload has the effect of reducing the gain in payload per trip that could be attributed to any increase in maximum axle-weight limits. To determine the effects of this payload increase, Method 2 was repeated as Method 3, but without the payload increase.

14. COMPARISON OF THE ECONOMY OF AXLE-WEIGHT LIMITS AS DETERMINED BY ANALYSIS METHODS 1, 1-M, 2, AND 3

At this point in the discussion it will be helpful to summarize briefly the evolution or sequence of the methods for determining the economy of maximum axle-weight limits and the distinguishing features of these methods. The major difference in approach is between Methods 1 and 2, or between (1) transferring the axle-weight distributions of States with the highest limits to the States having lower limits and (2) plotting the maximum practical gross vehicle weight for each vehicle class against equivalent 18,000-pound axles.

Methods 1, 2, and 3 were all done both with and without the 5-year transition period from 1965 to 1969. An evaluation of the results produced by all these methods indicated that the final benefit-cost ratios were lower when the transition period was included. This effect plus the fact that including such a period in the calculation is wholly logical led to the conclusion that the results with the transition period were superior to those without. Therefore, all the detailed results without the transition period are omitted from this report.

Comparing the results of Methods 1 and 2 revealed Method 1 as the preferred one. When it became clear that applying the AASHO design formulas in the three basic methods resulted in pavement depths less than the States are currently constructing, Method 1 was repeated as Method 1-M. Table 10-35 presents the design depths for rigid pavement and the benefit-cost ratios developed from Methods 1 and 1-M for the ten census divisions and the six highway systems.

A. Brief Summary of Table 10-35

The variations in incremental benefit-cost ratios from about 1.0 to about 60.0 shown in table 10-35 result from (1) the method of analysis, (2) the increment of increase in axle-weight limit, (3) the census division (variable in ADT, traffic composition, unit prices of construction cost, and soil character), and (4) highway system (variable in ADT and traffic composition).

The higher the axle-weight limit, the lower is the incremental benefit-cost ratio, but with the exception of eight entries in the secondary systems, all benefit-cost ratios for the increment of axle-weight limit from 24/41 to 26/44 are above 2.0. The low truck ADT on the secondary systems contributes to low benefit-cost ratios.

In table 10-35, for the New England and Middle Atlantic census divisions, all entries for the 18/32- and 20/35-kip axle-weight limits are for comparative purposes only,

Table 10-35. -- Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Headnote: Since the New England and Middle Atlantic census divisions in 1962 had axle-weight limits approximating the 22/38-kip limits, the entries in this table for 18/32 and 20/35 kips are backward and downward. They are included for comparison purposes only. Likewise, the entries for South Atlantic North and South Atlantic South for the 18/32-kip limits are projecting backward because these divisions had approximately 20/35-kip limits in 1962.

Sheet 1 of 6

Census division and analysis method		Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
		18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 1. Interstate rural														
1. NE	Method 1	7.81	8.09	8.35	8.59	8.80	13.6	12.1	10.7	7.7	13.6	12.9	12.2	11.2
	Method 1-M	8.66	8.83	9.00	9.17	9.32	17.1	14.7	12.5	8.9	17.1	15.9	14.8	13.4
2. MA	Method 1	9.04	9.35	9.64	9.91	10.09	11.7	10.1	8.7	6.5	11.7	10.9	10.2	9.3
	Method 1-M	9.04	9.35	9.64	9.91	10.09	11.7	10.1	8.7	6.5	11.7	10.9	10.2	9.3
3. SAN	Method 1	9.15	9.47	9.75	10.01	10.23	19.8	18.0	15.5	10.5	19.8	19.0	17.9	16.2
	Method 1-M	9.15	9.47	9.75	10.01	10.23	19.8	18.0	15.5	10.5	19.8	19.0	17.9	16.2
4. SAS	Method 1	7.58	7.86	8.11	8.34	8.55	16.9	14.3	11.7	7.5	16.9	15.6	14.4	12.8
	Method 1-M	8.87	9.00	9.13	9.26	9.39	26.2	20.9	16.3	10.0	26.2	23.5	21.1	18.4
5. ENC	Method 1	9.24	9.58	9.88	10.15	10.39	13.6	11.9	10.5	8.0	13.6	12.8	12.1	11.1
	Method 1-M	10.00	10.23	10.45	10.66	10.85	17.1	14.4	12.3	9.1	17.1	15.8	14.6	13.3
6. WNC	Method 1	7.61	7.84	8.05	8.24	8.40	5.1	4.7	3.7	2.7	5.1	4.9	4.5	4.1
	Method 1-M	9.00	9.11	9.21	9.30	9.39	7.7	6.7	5.1	3.5	7.7	7.2	6.5	5.8
7. ESC	Method 1	8.16	8.46	8.72	8.96	9.16	8.7	7.5	6.5	4.7	8.7	8.1	7.6	6.9
	Method 1-M	10.00	10.11	10.22	10.33	10.43	12.9	10.5	8.6	6.0	12.9	11.7	10.7	9.5
8. WSC	Method 1	8.96	9.27	9.54	9.78	9.99	9.3	8.1	6.5	3.9	9.3	8.7	8.0	7.1
	Method 1-M	9.00	9.30	9.57	9.80	10.01	9.4	8.2	6.5	4.0	9.4	8.8	8.1	7.2
9. M	Method 1	7.21	7.40	7.57	7.74	7.89	6.0	5.2	4.3	2.9	6.0	5.6	5.2	4.6
	Method 1-M	8.00	8.11	8.22	8.33	8.44	8.0	6.7	5.3	3.5	8.0	7.4	6.7	5.9
10. P	Method 1	9.25	9.52	9.77	10.00	10.20	12.8	10.1	7.7	4.8	12.8	11.5	10.3	9.0
	Method 1-M	9.25	9.52	9.77	10.00	10.20	12.8	10.1	7.7	4.8	12.8	11.5	10.3	9.0

Table 10-35. -- Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 2 of 6

Census division and analysis method		Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
		18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 2. Interstate urban														
1. NE	Method 1	8.19	8.41	8.61	8.79	8.95	45.3	37.4	29.9	18.3	45.3	41.4	37.7	33.1
	Method 1-M	8.68	8.85	9.00	9.15	9.28	49.8	40.6	32.0	19.3	49.8	45.2	40.9	35.7
2. MA	Method 1	9.49	9.69	9.88	10.07	10.24	39.5	32.0	24.9	15.0	39.5	35.7	32.2	28.0
	Method 1-M	9.49	9.69	9.88	10.07	10.24	39.5	32.0	24.9	15.0	39.5	35.7	32.2	28.0
3. SAN	Method 1	9.02	9.22	9.40	9.57	9.73	20.4	17.8	15.2	10.8	20.4	19.1	17.8	16.1
	Method 1-M	9.02	9.22	9.40	9.57	9.73	20.4	17.8	15.2	10.8	20.4	19.1	17.8	16.1
4. SAS	Method 1	7.83	8.03	8.22	8.40	8.56	24.2	21.2	18.0	13.0	24.2	22.7	21.2	19.3
	Method 1-M	8.89	9.00	9.11	9.22	9.32	30.9	26.2	21.9	15.3	30.9	28.6	26.4	23.6
5. ENC	Method 1	9.11	9.32	9.51	9.69	9.85	23.7	20.9	17.9	12.9	23.7	22.3	20.9	19.0
	Method 1-M	10.00	10.13	10.26	10.39	10.50	27.5	23.8	19.9	14.2	27.5	25.6	23.7	21.4
6. WNC	Method 1	7.76	7.93	8.10	8.26	8.40	11.7	9.7	7.7	4.8	11.7	10.7	9.8	8.6
	Method 1-M	9.00	9.08	9.17	9.25	9.34	14.3	11.7	9.1	5.6	14.3	13.0	11.7	10.2
7. ESC	Method 1	9.37	9.55	9.72	9.89	10.05	24.8	21.3	17.9	12.4	24.8	23.1	21.4	19.2
	Method 1-M	10.00	10.13	10.26	10.39	10.52	27.1	23.1	19.2	13.2	27.1	25.1	23.2	20.7
8. WSC	Method 1	8.48	8.68	8.86	9.03	9.19	17.8	15.3	12.8	8.8	17.8	16.6	15.4	13.8
	Method 1-M	9.00	9.15	9.30	9.43	9.55	19.5	16.6	13.7	9.4	19.5	18.1	16.6	14.9
9. M	Method 1	8.44	8.62	8.79	8.95	9.10	22.1	18.6	15.0	8.9	22.1	20.4	18.7	16.3
	Method 1-M	8.44	8.62	8.79	8.95	9.10	22.2	18.5	15.0	8.9	22.2	20.4	18.7	16.3
10. P	Method 1	9.51	9.68	9.85	10.02	10.17	29.8	24.8	20.4	14.3	29.8	27.3	25.0	22.4
	Method 1-M	9.51	9.68	9.85	10.02	10.17	29.8	24.8	20.4	14.3	29.8	27.3	25.0	22.4

Table 10-35. -- Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 3 of 6

Census division and analysis method		Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
		18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 3. Primary rural														
1. NE	Method 1	6.30	6.52	6.73	6.92	7.09	8.9	7.8	6.8	4.4	8.9	8.4	7.9	7.1
	Method 1-M	8.92	8.96	9.00	9.05	9.09	26.2	21.2	16.7	9.9	26.2	23.7	21.3	18.4
2. MA	Method 1	7.06	7.30	7.51	7.70	7.87	7.9	7.4	7.1	5.4	7.9	7.7	7.5	7.0
	Method 1-M	8.84	8.92	9.00	9.08	9.15	18.7	16.1	14.0	10.0	18.7	17.4	16.3	14.8
3. SAN	Method 1	7.10	7.34	7.56	7.74	7.90	8.4	7.9	7.1	5.0	8.4	8.2	7.9	7.3
	Method 1-M	8.92	9.00	9.08	9.16	9.23	18.4	15.6	12.8	8.4	18.4	17.0	15.6	13.9
4. SAS	Method 1	6.49	6.70	6.88	7.04	7.19	8.6	7.8	6.7	4.3	8.6	8.2	7.8	7.1
	Method 1-M	8.96	9.00	9.04	9.09	9.13	25.9	21.2	16.5	9.7	25.9	23.6	21.2	18.4
5. ENC	Method 1	6.97	7.21	7.43	7.61	7.77	8.7	8.1	7.2	4.9	8.7	8.4	8.0	7.4
	Method 1-M	10.00	10.04	10.08	10.13	10.16	33.3	27.4	21.6	13.6	33.3	30.3	27.4	24.2
6. WNC	Method 1	5.99	6.20	6.39	6.56	6.70	6.4	5.7	4.9	3.0	6.4	6.1	5.7	5.2
	Method 1-M	9.00	9.03	9.06	9.09	9.12	24.3	19.1	15.1	8.0	24.3	21.7	19.5	16.6
7. ESC	Method 1	6.69	6.92	7.13	7.32	7.49	11.2	9.7	8.0	4.8	11.2	10.5	9.7	8.6
	Method 1-M	10.00	10.03	10.06	10.10	10.13	35.7	28.3	21.4	12.0	35.7	32.0	28.4	24.3
8. WSC	Method 1	6.95	7.18	7.37	7.53	7.67	14.3	13.3	11.2	6.7	14.3	13.8	13.1	11.8
	Method 1-M	9.00	9.06	9.13	9.18	9.24	35.6	29.4	22.7	12.5	35.6	32.5	29.3	25.4
9. M	Method 1	5.51	5.71	5.90	6.06	6.21	6.6	5.7	4.6	2.5	6.6	6.2	5.7	5.0
	Method 1-M	8.00	8.03	8.07	8.10	8.14	26.9	20.4	15.4	7.3	26.9	23.6	20.9	17.4
10. P	Method 1	6.94	7.19	7.40	7.58	7.73	6.1	5.6	4.9	3.2	6.1	5.9	5.6	5.1
	Method 1-M	9.00	9.07	9.14	9.20	9.26	13.3	11.0	9.0	5.4	13.3	12.2	11.1	9.8

Table 10-35. -- Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 4 of 6

Census division and analysis method		Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
		18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 4. Primary urban														
1. NE	Method 1	6.69	6.90	7.09	7.25	7.40	30.2	26.0	21.9	13.4	30.2	28.2	26.2	23.3
	Method 1-M	8.90	8.95	9.00	9.05	9.10	54.3	44.0	34.7	20.0	54.3	49.2	44.4	38.4
2. MA	Method 1	7.13	7.36	7.57	7.76	7.93	35.7	30.5	26.1	16.1	35.7	33.1	30.9	27.6
	Method 1-M	8.84	8.92	9.00	9.08	9.16	65.8	52.1	41.8	24.4	65.8	58.8	53.2	46.1
3. SAN	Method 1	7.38	7.62	7.84	8.05	8.24	31.1	24.8	18.5	8.9	31.1	28.0	24.9	21.2
	Method 1-M	8.91	9.00	9.10	9.20	9.30	48.7	36.6	26.4	12.1	48.7	42.6	37.1	30.8
4. SAS	Method 1	6.49	6.68	6.85	7.01	7.16	23.1	19.6	15.3	8.4	23.1	21.4	19.5	17.0
	Method 1-M	8.96	9.00	9.04	9.08	9.12	54.2	42.1	31.4	16.0	54.2	48.1	42.5	35.9
5. ENC	Method 1	7.16	7.39	7.60	7.78	7.93	22.4	17.7	13.1	6.4	22.4	20.2	18.0	15.5
	Method 1-M	10.00	10.05	10.09	10.14	10.18	48.9	35.9	24.4	11.1	48.9	42.4	36.4	30.2
6. WNC	Method 1	6.58	6.81	7.01	7.20	7.36	26.9	21.9	16.2	7.3	26.9	24.6	22.0	18.9
	Method 1-M	9.00	9.05	9.10	9.15	9.20	78.8	57.3	39.7	15.9	78.8	68.0	58.7	48.0
7. ESC	Method 1	7.57	7.82	8.04	8.24	8.40	59.4	45.4	30.6	13.1	59.4	52.7	46.0	39.0
	Method 1-M	10.00	10.06	10.13	10.19	10.25	135.0	95.2	58.8	23.6	135.0	115.3	96.6	79.1
8. WSC	Method 1	7.16	7.38	7.57	7.75	7.90	43.3	33.9	24.4	12.0	43.3	38.8	34.3	29.4
	Method 1-M	9.00	9.07	9.14	9.21	9.28	81.1	59.0	39.7	18.4	81.1	70.2	60.0	49.9
9. M	Method 1	7.26	7.51	7.74	7.94	8.10	43.1	37.6	29.5	16.8	43.1	40.5	37.2	33.0
	Method 1-M	8.00	8.16	8.31	8.46	8.58	63.6	52.7	39.1	21.3	63.6	58.3	52.2	45.4
10. P	Method 1	8.37	8.57	8.75	8.92	9.06	31.8	25.0	18.7	9.7	31.8	28.5	25.3	21.6
	Method 1-M	9.00	9.14	9.27	9.40	9.51	35.6	27.6	20.3	10.4	35.6	31.7	27.9	23.7

Table 10-35. -- Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 5 of 6

Census division and analysis method		Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
		18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 5. Secondary rural														
1. NE	Method 1	5.01	5.11	5.22	5.33	5.44	15.6	12.5	10.3	6.7	15.6	14.0	12.8	11.3
	Method 1-M	7.98	7.99	8.00	8.01	8.03	80.3	72.2	48.4	29.9	80.3	76.4	66.0	56.2
2. MA	Method 1	5.01	5.11	5.22	5.33	5.44	13.2	10.4	8.8	5.6	13.2	11.8	10.8	9.5
	Method 1-M	7.98	7.99	8.00	8.01	8.03	70.3	52.2	40.8	24.0	70.3	60.7	53.5	45.4
3. SAN	Method 1	4.76	4.86	4.98	5.10	5.22	7.6	5.6	4.4	2.8	7.6	6.6	5.8	5.0
	Method 1-M	7.99	8.00	8.01	8.02	8.04	45.5	32.7	24.6	14.0	45.5	38.7	33.5	27.9
4. SAS	Method 1	4.56	4.66	4.77	4.89	5.00	6.9	5.3	4.1	2.7	6.9	6.1	5.4	4.7
	Method 1-M	7.99	8.00	8.01	8.02	8.03	28.2	23.4	17.9	11.5	28.2	25.8	23.1	20.1
5. ENC	Method 1	5.17	5.30	5.41	5.52	5.61	5.4	4.8	3.8	2.2	5.4	5.1	4.7	4.2
	Method 1-M	8.00	8.02	8.03	8.05	8.06	26.9	23.7	15.7	8.4	26.9	25.4	22.1	18.7
6. WNC	Method 1	5.04	5.17	5.28	5.38	5.47	4.9	4.2	3.4	1.9	4.9	4.5	4.2	3.7
	Method 1-M	8.00	8.01	8.03	8.04	8.05	26.9	21.1	14.9	7.2	26.9	24.0	20.9	17.2
7. ESC	Method 1	5.17	5.30	5.41	5.52	5.61	4.2	3.5	2.8	1.6	4.2	3.8	3.5	3.1
	Method 1-M	8.00	8.02	8.03	8.05	8.06	12.1	9.5	7.3	3.6	12.1	10.8	9.6	8.1
8. WSC	Method 1	5.17	5.30	5.41	5.52	5.61	5.8	5.0	4.1	2.3	5.8	5.4	5.0	4.4
	Method 1-M	8.00	8.02	8.03	8.05	8.06	24.3	19.0	14.2	6.8	24.3	21.6	19.1	15.9
9. M	Method 1	4.88	5.00	5.11	5.21	5.30	6.5	5.5	4.6	2.6	6.5	6.0	5.6	4.9
	Method 1-M	8.00	8.01	8.02	8.03	8.04	44.1	31.6	25.7	11.0	44.1	37.6	33.7	27.4
10. P	Method 1	4.95	5.07	5.19	5.29	5.38	5.8	4.9	4.0	2.3	5.8	5.4	5.0	4.4
	Method 1-M	8.00	8.01	8.02	8.03	8.05	25.5	21.1	14.2	7.9	25.5	23.4	20.1	17.2

Table 10-35. -- Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 6 of 6

Census division and analysis method		Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
		18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 6. Secondary urban														
1. NE	Method 1	5.29	5.44	5.59	5.73	5.85	10.2	8.2	6.4	3.7	10.2	9.2	8.3	7.2
	Method 1-M	7.96	7.98	8.00	8.02	8.05	13.9	11.0	8.4	4.7	13.9	12.4	11.1	9.5
2. MA	Method 1	5.56	5.69	5.83	5.95	6.07	8.4	6.6	5.3	2.7	8.4	7.5	6.8	5.8
	Method 1-M	7.95	7.97	8.00	8.03	8.05	11.0	8.6	6.6	3.4	11.0	9.8	8.7	7.4
3. SAN	Method 1	6.05	6.24	6.41	6.55	6.67	6.0	5.3	4.2	2.4	6.0	5.6	5.2	4.5
	Method 1-M	7.95	8.00	8.05	8.10	8.14	8.1	6.9	5.3	2.9	8.1	7.5	6.8	5.9
4. SAS	Method 1	5.43	5.57	5.71	5.85	5.98	3.9	3.3	3.0	1.9	3.9	3.6	3.4	3.0
	Method 1-M	7.98	8.00	8.02	8.05	8.08	5.0	4.2	3.7	2.4	5.0	4.6	4.3	3.8
5. ENC	Method 1	5.50	5.65	5.79	5.94	6.06	2.5	2.2	1.9	1.3	2.5	2.4	2.2	2.0
	Method 1-M	8.00	8.03	8.05	8.08	8.11	3.2	2.8	2.4	1.6	3.2	3.0	2.8	2.5
6. WNC	Method 1	4.75	4.87	4.99	5.11	5.22	2.4	2.2	1.7	1.1	2.4	2.3	2.1	1.9
	Method 1-M	8.00	8.01	8.02	8.03	8.04	3.9	3.5	2.6	1.7	3.9	3.7	3.3	2.9
7. ESC	Method 1	5.76	5.90	6.02	6.15	6.26	2.0	1.8	1.4	0.9	2.0	1.9	1.7	1.5
	Method 1-M	8.00	8.03	8.06	8.09	8.12	2.3	2.1	1.6	1.0	2.3	2.2	2.0	1.8
8. WSC	Method 1	5.48	5.63	5.78	5.92	6.05	2.6	2.2	1.9	1.4	2.6	2.4	2.3	2.0
	Method 1-M	8.00	8.03	8.05	8.08	8.11	3.1	2.7	2.3	1.6	3.1	2.9	2.7	2.4
9. M	Method 1	6.11	6.29	6.45	6.59	6.71	9.5	8.1	6.7	4.3	9.5	8.8	8.1	7.3
	Method 1-M	8.00	8.05	8.10	8.14	8.19	14.6	11.8	9.4	5.7	14.6	13.2	11.9	10.4
10. P	Method 1	6.57	6.74	6.90	7.04	7.17	3.1	2.6	2.2	1.4	3.1	2.9	2.6	2.3
	Method 1-M	8.00	8.07	8.13	8.20	8.26	3.4	2.8	2.3	1.5	3.4	3.1	2.8	2.5

because these two census divisions now have axle-weight limits approximately equal to 22/38 kips. The same is true for the 20/35-kip limits for the South Atlantic North and South Atlantic South divisions, which now have axle-weight limits approximating 20/35 kips.

B. Results of Method 1-M Analysis

Where the minimum depth of pavement used in Method 1-M is equal to or less than that for Method 1 at the base condition, the pavement depth and the benefit-cost ratios are identical for the two methods. Where the minimum depth of pavement surface used in Method 1-M is greater than the depth at the base condition in Method 1, the pavement depths for Method 1-M and the resulting benefit-cost ratios are always greater than for Method 1.

This analysis (Method 1-M) again brings out the following significant facts: (1) As the daily E 18-kip axle applications increase, the pavement design depth increases at a decreasing rate, and (2) as the design pavement depth increases, the cost of the pavement per cubic yard decreases, but the total pavement cost per mile increases at a decreasing rate. From these facts, logical reasoning leads to the conclusion that, as axle-weight limits are increased, the use of a minimum pavement depth above that resulting from the Method 1 design would lead to greater economy (benefit-cost ratio) than would result from Method 1. Table 10-35 proves the correctness of this reasoning.

The benefit-cost ratios of Method 1-M vary from equality with those of Method 1 to as much as six times as great. For a given highway system now using the minimum pavement depth in Method 1-M, the economy of higher axle-weight limits as given in table 10-35 would be more nearly that of Method 1-M than of Method 1.

This analysis should allay all fears that, because Method 1 procedures result in pavement design of much less depth than is commonly used by some highway departments, the analysis unjustly favors higher axle-weight limits. The exact opposite is true.

C. The Transition Period

Should the laws of all States, or of any State, be changed to legally permit axle weights higher than are now permitted, the trucking industry would not make full use of the higher limits the first day or even the first year they were legally effective. Of course, the amount of increase in the limits would be a factor determining the rate of utilization of the higher limits. The change from 18/32 kips to 20/34 kips could be rather fully utilized within a year, but the change from 18/32 to 26/44 kips would require some years to be fully effective. The change in axle-weight limits would affect vehicle design, customer orders, commodity selection, terminal facilities, and practically every aspect of the trucking industry. In the analyses of the economy of axle-weight limits the transition period was included as described under Method 1.

The use of the transition period has the effect of postponing the utilization of the increasing axle-weight limits, and therefore, for the 20-year analysis period used, the design pavement depth should be slightly less with the transition period than without. The E 18-kip axle applications in the 20-year period would be fewer because of the time delay in applying the axles of higher weight. The total motor vehicle operating cost reduction would be less with the transition period than without. Therefore, the overall economy of the higher axle weights within the 20-year analysis period is less with the transition period than without it.

The effect of using the transition period for the axle-weight limits of 20/35 to 24/41 kips is minor, amounting to practically zero for the increment of 18/32 to 20/35 kips, and increasing gradually to the axle limit of 24/41. Between 24/41 and 26/44 kips the effect of the 2-year differential is pronounced. For rigid pavement and the upper two weight-limit intervals, the following table gives the benefit-cost ratios with the transition period expressed as a percentage of the benefit-cost ratio without the transition period:

	Axle-weight-limit interval			
	22/38 to 24/41 kips		24/41 to 26/44 kips	
	Minimum*	Maximum*	Minimum*	Maximum*
1. Interstate rural	87.5	89.6	63.9	73.0
2. Interstate urban	87.7	90.9	66.7	73.9
3. Primary rural	86.1	88.9	59.5	66.7
4. Primary urban	85.2	88.9	54.1	62.9
5. Secondary rural	86.6	90.2	61.3	66.7
6. Secondary urban	82.4	89.5	54.0	63.6

* Considering all ten census divisions

D. Effect of the 29-Percent Increase in Payload Per Vehicle, 1962 to 1990

From table 10-37 the effect of the increase in payload per vehicle from 1962 to 1990 may be determined by comparing the rigid pavement depths and benefit-cost ratios of Method 3 (without payload increase) with those of Method 2 (with payload increase).

Two sets of benefit-cost ratios are shown below:

	Method 2 with payload increase	Method 3, without payload increase
System 1, New England at 26/44 axle-weight limit		
Rigid pavement depth, inches	8.52	8.47
Benefit-cost ratio	9.4	12.8
System 3, East North Central at 26/44 axle-weight limit		
Rigid pavement depth, inches	7.40	7.29
Benefit-cost ratio	8.0	13.0

Table 10-37.--Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Headnote: Since the New England and Middle Atlantic census divisions in 1962 had axle-weight limits approximating the 22/38-kip limits, the entries in this table for 18/32 and 20/35 kips are projecting backward and downward. They are included for comparison purposes only. Likewise, the entries for South Atlantic North and South Atlantic South for the 18/32-kip limits are projecting backward because these divisions had approximately 20/35-kip limits in 1962.

Sheet 1 of 7

Census division and analysis method			Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
			18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 1. Interstate rural															
1.	NE	Method 1	7.81	8.09	8.35	8.59	8.80	13.6	12.1	10.7	7.7	13.6	12.9	12.2	11.2
		Method 2	8.19	8.27	8.35	8.44	8.52	25.0	18.6	14.7	9.4	25.0	21.8	19.4	16.9
		Method 3	8.26	8.30	8.35	8.41	8.47	33.1	24.7	19.5	12.8	33.1	28.9	25.7	22.4
2.	MA	Method 1	9.04	9.35	9.64	9.91	10.09	11.7	10.1	8.7	6.5	11.7	10.9	10.2	9.3
		Method 2	9.45	9.55	9.64	9.74	9.83	24.0	17.8	13.9	8.7	24.0	20.9	18.6	16.1
		Method 3	9.54	9.59	9.64	9.70	9.75	30.6	22.7	17.8	11.6	30.6	26.6	23.7	20.6
3.	SAN	Method 1	9.15	9.47	9.75	10.01	10.23	19.8	18.0	15.5	10.5	19.8	19.0	17.9	16.2
		Method 2	9.34	9.47	9.60	9.73	9.86	41.8	31.3	25.0	16.0	41.8	36.5	32.7	28.5
		Method 3	9.39	9.47	9.55	9.64	9.74	56.3	42.1	33.5	22.2	56.3	49.1	43.9	38.3
4.	SAS	Method 1	7.58	7.86	8.11	8.34	8.55	16.9	14.3	11.7	7.5	16.9	15.6	14.4	12.8
		Method 2	7.73	7.86	7.98	8.09	8.20	29.1	22.5	18.4	12.3	29.1	25.8	23.4	20.7
		Method 3	7.77	7.86	7.94	8.02	8.10	41.6	32.0	26.2	17.9	41.6	36.8	33.3	29.4
5.	ENC	Method 1	9.24	9.58	9.86	10.15	10.39	13.6	11.9	10.5	8.0	13.6	12.8	12.1	11.1
		Method 2	9.24	9.45	9.63	9.79	9.93	39.8	32.5	27.2	21.3	39.8	36.3	33.4	30.7
		Method 3	9.24	9.38	9.51	9.61	9.71	57.8	46.7	39.6	32.0	57.8	52.4	48.4	44.6
6.	WNC	Method 1	7.61	7.84	8.05	8.24	8.40	5.1	4.7	3.7	2.7	5.1	4.9	4.5	4.1
		Method 2	7.61	7.77	7.91	8.04	8.15	15.2	12.4	10.0	6.7	15.2	13.8	12.6	11.3
		Method 3	7.61	7.72	7.82	7.90	7.96	21.5	17.8	14.8	10.5	21.5	19.7	18.2	16.5
7.	ESC	Method 1	8.16	8.46	8.72	8.96	9.16	8.7	7.5	6.5	4.7	8.7	8.1	7.6	6.9
		Method 2	8.16	8.29	8.41	8.54	8.65	17.5	13.6	11.0	7.2	17.5	15.6	14.1	12.4
		Method 3	8.16	8.24	8.33	8.41	8.49	23.4	18.0	14.7	9.8	23.4	20.7	18.7	16.5
8.	WSC	Method 1	8.96	9.27	9.54	9.78	9.99	9.3	8.1	6.5	3.9	9.3	8.7	8.0	7.1
		Method 2	8.96	9.16	9.33	9.48	9.61	34.0	27.4	22.3	15.0	34.0	30.8	28.1	25.1
		Method 3	8.96	9.09	9.20	9.30	9.38	48.4	38.8	31.8	22.1	48.4	43.7	39.9	35.7

Table 10-37.--Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 2 of 7

Census division and analysis method			Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
			18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 1. Interstate rural--continued															
9.	M	Method 1	7.21	7.40	7.57	7.74	7.89	6.0	5.2	4.3	2.9	6.0	5.6	5.2	4.6
		Method 2	7.21	7.41	7.55	7.72	7.85	15.0	12.5	10.6	7.4	15.0	13.8	12.8	11.6
		Method 3	7.21	7.35	7.47	7.56	7.64	22.2	18.8	16.5	12.4	22.2	20.6	19.4	17.9
10.	P	Method 1	9.25	9.52	9.77	10.00	10.20	12.8	10.1	7.7	4.8	12.8	11.5	10.3	9.0
		Method 2	9.25	9.60	9.88	10.11	10.29	25.9	21.8	18.5	12.8	25.9	24.0	22.3	20.2
		Method 3	9.25	9.50	9.70	9.06	9.99	37.1	31.9	28.5	16.6	37.1	34.2	32.4	28.9
System 2. Interstate urban															
1.	NE	Method 1	8.19	8.41	8.61	8.79	8.95	45.3	37.4	29.9	18.3	45.3	41.4	37.7	33.1
		Method 2	8.44	8.52	8.61	8.69	8.77	20.3	16.1	13.5	9.5	20.3	18.2	16.6	14.8
		Method 3	8.50	8.55	8.61	8.66	8.71	25.9	20.7	17.4	12.6	25.9	23.3	21.4	19.2
2.	MA	Method 1	9.49	9.69	9.88	10.07	10.24	39.5	32.0	24.9	15.0	39.5	35.7	32.2	28.0
		Method 2	9.69	9.79	9.88	9.96	10.07	20.9	16.1	13.3	8.7	20.9	18.5	16.8	14.8
		Method 3	9.77	9.83	9.88	9.94	9.99	26.3	20.5	16.9	12.0	26.3	23.4	21.2	18.9
3.	SAN	Method 1	9.02	9.22	9.40	9.57	9.73	20.4	17.8	15.2	10.8	20.4	19.1	17.8	16.1
		Method 2	9.09	9.22	9.34	9.46	9.57	19.8	15.6	12.7	8.9	19.8	17.7	16.1	14.3
		Method 3	9.13	9.22	9.31	9.39	9.48	25.1	19.8	16.3	11.7	25.1	22.4	20.4	18.2
4.	SAS	Method 1	7.83	8.03	8.22	8.40	8.56	24.2	21.2	18.0	13.0	24.2	22.7	21.2	19.3
		Method 2	7.91	8.03	8.14	8.24	8.34	22.6	18.1	15.2	10.9	22.6	20.4	18.7	16.8
		Method 3	7.94	8.03	8.11	8.19	8.26	30.2	24.2	20.3	14.9	30.2	27.2	25.0	22.5
5.	ENC	Method 1	9.11	9.32	9.51	9.69	9.85	23.7	20.9	17.9	12.9	23.7	22.3	20.9	19.0
		Method 2	9.11	9.29	9.45	9.60	9.74	26.2	20.9	17.3	12.2	26.2	23.6	21.5	19.3
		Method 3	9.11	9.25	9.37	9.47	9.57	33.9	27.7	23.6	17.3	33.9	30.9	28.5	25.8
6.	WNC	Method 1	7.76	7.93	8.10	8.26	8.40	11.7	9.7	7.7	4.8	11.7	10.7	9.8	8.6
		Method 2	7.76	7.91	8.05	8.18	8.30	11.6	9.2	7.7	5.3	11.6	10.4	9.5	8.5
		Method 3	7.76	7.89	7.99	8.08	8.15	14.9	12.2	10.4	7.6	14.9	13.6	12.6	11.4
7.	ESC	Method 1	9.37	9.55	9.72	9.89	10.05	24.8	21.3	17.9	12.4	24.8	23.1	21.4	19.2
		Method 2	9.37	9.50	9.62	9.75	9.87	27.5	21.5	17.7	12.1	27.5	24.5	22.3	19.7
		Method 3	9.37	9.43	9.56	9.65	9.73	34.8	27.8	23.4	16.8	34.8	31.3	28.7	25.8

Table 10-37.--Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 3 of 7

Census division and analysis method			Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
			18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
		System 2. Interstate urban--continued													
8.	WSC	Method 1	8.48	8.68	8.86	9.03	9.19	17.8	15.3	12.8	8.8	17.8	16.6	15.4	13.8
		Method 2	8.48	8.63	8.78	8.91	9.04	20.6	16.4	13.6	9.5	20.6	18.5	16.9	15.1
		Method 3	8.48	8.60	8.70	8.79	8.86	26.9	21.9	19.2	13.2	26.9	24.5	22.8	20.4
9.	M	Method 1	8.44	8.62	8.79	8.95	9.10	22.1	18.6	15.0	8.9	22.1	20.4	18.7	16.3
		Method 2	8.44	8.64	8.82	8.99	9.14	26.6	21.4	17.9	12.7	26.6	24.0	22.1	19.9
		Method 3	8.44	8.60	8.74	8.85	8.94	35.6	29.7	25.9	19.5	35.6	32.8	30.6	28.1
10.	P	Method 1	9.51	9.68	9.85	10.02	10.17	29.8	24.8	20.4	14.3	29.8	27.3	25.0	22.4
		Method 2	9.51	9.77	10.00	10.20	10.40	25.8	20.8	17.4	12.5	25.8	23.3	21.4	19.3
		Method 3	9.51	9.74	9.92	10.07	10.19	32.8	27.1	23.7	17.7	32.8	30.0	28.0	25.6
		System 3. Primary rural													
1.	NE	Method 1	6.30	6.52	6.73	6.92	7.09	8.9	7.8	6.8	4.4	8.9	8.4	7.9	7.1
		Method 2	6.60	6.66	6.73	6.80	6.86	20.5	15.2	11.8	6.6	20.5	17.8	15.8	13.5
		Method 3	6.64	6.68	6.73	6.78	6.83	27.8	20.7	15.8	9.4	27.8	24.2	2.14	18.3
2.	MA	Method 1	7.06	7.30	7.51	7.70	7.87	7.9	7.4	7.1	5.4	7.9	7.7	7.5	7.0
		Method 2	7.38	7.45	7.51	7.58	7.65	40.6	29.3	22.5	12.7	40.6	34.9	30.7	26.2
		Method 3	7.43	7.47	7.51	7.57	7.62	60.6	42.8	31.6	18.6	60.6	51.5	44.5	37.7
3.	SAN	Method 1	7.10	7.34	7.56	7.74	7.90	8.4	7.9	7.1	5.0	8.4	8.2	7.9	7.3
		Method 2	7.25	7.34	7.43	7.52	7.60	24.6	18.9	15.4	9.1	24.6	21.8	19.7	17.1
		Method 3	7.29	7.34	7.41	7.47	7.54	36.5	26.7	20.8	12.5	36.5	31.6	27.9	23.9
4.	SAS	Method 1	6.49	6.70	6.88	7.04	7.19	8.6	7.8	6.7	4.3	8.6	8.2	7.8	7.1
		Method 2	6.61	6.70	6.78	6.86	6.93	21.5	16.3	13.2	8.0	21.5	18.9	17.0	14.9
		Method 3	6.64	6.70	6.75	6.81	6.87	32.5	24.0	19.0	11.8	32.5	28.2	25.1	21.7
5.	ENC	Method 1	6.97	7.21	7.43	7.61	7.77	8.7	8.1	7.2	4.9	8.7	8.4	8.0	7.4
		Method 2	6.97	7.10	7.22	7.32	7.40	17.1	14.4	12.4	8.0	17.1	15.8	14.8	13.4
		Method 3	6.97	7.07	7.16	7.23	7.29	24.2	20.5	18.7	13.0	24.2	22.5	21.4	19.7
6.	WNC	Method 1	5.99	6.20	6.39	6.56	6.70	6.4	5.7	4.9	3.0	6.4	6.1	5.7	5.2
		Method 2	5.99	6.11	6.21	6.30	6.38	10.9	8.9	7.7	5.0	10.9	10.0	9.3	8.4
		Method 3	5.99	6.09	6.17	6.23	6.28	14.5	12.5	11.4	8.1	14.5	13.5	12.9	12.0

Table 10-37.--Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 4 of 7

Census division and analysis method			Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
			18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 3. Primary rural--continued															
7.	ESC	Method 1	6.69	6.92	7.13	7.32	7.49	11.2	9.7	8.0	4.8	11.2	10.5	9.7	8.6
		Method 2	6.69	6.80	6.89	6.97	7.04	19.9	16.7	13.9	8.6	19.9	18.4	17.0	15.1
		Method 3	6.69	6.78	6.85	6.91	6.96	25.7	22.0	18.8	12.5	25.7	24.0	22.4	20.3
8.	WSC	Method 1	6.95	7.18	7.37	7.53	7.67	14.3	13.3	11.2	6.7	14.3	13.8	13.1	11.8
		Method 2	6.95	7.09	7.20	7.30	7.38	26.8	22.6	19.9	12.6	26.8	24.8	23.4	21.1
		Method 3	6.95	7.05	7.14	7.21	7.26	38.0	32.6	28.3	19.8	38.0	35.4	33.3	30.6
9.	M	Method 1	5.51	5.71	5.90	6.06	6.21	6.6	5.7	4.6	2.5	6.6	6.2	5.7	5.0
		Method 2	5.51	5.65	5.76	5.86	5.94	9.3	8.4	7.4	5.1	9.3	8.9	8.5	7.8
		Method 3	5.51	5.62	5.70	5.77	5.82	13.1	12.5	11.6	9.2	13.1	12.9	12.5	11.9
10.	P	Method 1	6.94	7.19	7.40	7.58	7.73	6.1	5.6	4.9	3.2	6.1	5.9	5.6	5.1
		Method 2	6.94	7.14	7.30	7.43	7.55	11.7	10.1	8.6	5.7	11.7	11.0	10.3	9.3
		Method 3	6.94	7.09	7.21	7.31	7.38	16.5	14.4	12.3	9.5	16.5	15.5	14.6	13.6
System 4. Primary urban															
1.	NE	Method 1	6.69	6.90	7.09	7.25	7.40	30.2	26.0	21.9	13.4	30.2	28.2	26.2	23.3
		Method 2	6.93	7.01	7.09	7.16	7.23	17.8	14.1	11.6	7.5	17.8	15.9	14.5	12.8
		Method 3	6.96	7.02	7.09	7.15	7.20	21.8	17.3	14.4	9.6	21.8	19.6	17.9	15.9
2.	MA	Method 1	7.13	7.36	7.57	7.76	7.93	35.7	30.5	26.1	16.1	35.7	33.1	30.9	27.6
		Method 2	7.39	7.48	7.57	7.66	7.74	29.8	22.8	18.6	11.7	29.8	26.3	23.7	20.8
		Method 3	7.44	7.50	7.57	7.64	7.70	38.8	29.7	24.3	15.8	38.8	34.2	30.9	27.2
3.	SAN	Method 1	7.38	7.62	7.84	8.05	8.24	31.1	24.8	18.5	8.9	31.1	28.0	24.9	21.2
		Method 2	7.51	7.62	7.72	7.82	7.91	21.3	16.7	13.7	8.7	21.3	19.0	17.3	15.2
		Method 3	7.54	7.62	7.70	7.77	7.85	27.6	21.4	17.5	11.5	27.6	24.5	22.2	19.6
4.	SAS	Method 1	6.49	6.68	6.85	7.01	7.16	23.1	19.6	15.3	8.4	23.1	21.4	19.5	17.0
		Method 2	6.58	6.68	6.77	6.86	6.94	17.1	13.6	11.4	7.4	17.1	15.4	14.1	12.5
		Method 3	8.95	9.06	9.17	9.26	9.35	19.3	14.6	13.1	9.1	19.3	16.9	15.7	14.2
5.	ENC	Method 1	7.16	7.39	7.60	7.78	7.93	22.4	17.7	13.1	6.4	22.4	20.2	18.0	15.5
		Method 2	7.16	7.29	7.42	7.54	7.65	15.5	12.3	10.3	6.6	15.5	13.9	12.8	11.3
		Method 3	7.16	7.28	7.39	7.48	7.55	18.8	15.8	13.9	9.6	18.8	17.4	16.3	14.8

Table 10-37.--Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 5 of 7

Census division and analysis method			Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
			18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 4. Primary urban--continued															
6.	WNC	Method 1	6.58	6.81	7.01	7.20	7.36	26.9	21.9	16.2	7.3	26.9	24.6	22.0	18.9
		Method 2	6.58	6.71	6.83	6.94	7.04	21.2	17.4	14.6	9.5	21.2	19.4	17.9	16.0
		Method 3	6.58	6.70	6.80	6.89	6.95	25.3	23.0	20.9	15.6	25.3	24.2	23.3	21.7
7.	ESC	Method 1	7.57	7.82	8.04	8.24	8.40	59.4	45.4	30.6	13.1	59.4	52.7	46.0	39.0
		Method 2	7.57	7.70	7.82	7.93	8.03	40.4	32.6	27.1	17.5	40.4	36.6	33.6	29.8
		Method 3	7.57	7.68	7.78	7.87	7.95	50.4	42.0	36.4	24.5	50.4	46.4	43.3	39.0
8.	WSC	Method 1	7.16	7.38	7.57	7.75	7.90	43.3	33.9	24.4	12.0	43.3	38.8	34.3	29.4
		Method 2	7.16	7.29	7.41	7.52	7.62	30.8	24.9	20.2	13.2	30.8	27.9	25.4	22.6
		Method 3	7.16	7.28	7.37	7.45	7.52	38.1	32.7	27.6	20.0	38.1	35.6	33.1	30.2
9.	M	Method 1	7.26	7.51	7.74	7.94	8.10	43.1	37.6	29.5	16.8	43.1	40.5	37.2	33.0
		Method 2	7.26	7.43	7.59	7.73	7.87	39.9	31.2	29.0	18.7	39.9	35.7	33.6	30.3
		Method 3	7.26	7.42	7.54	7.65	7.73	50.4	46.5	42.9	33.7	50.4	48.6	47.0	44.5
10.	P	Method 1	8.37	8.57	8.75	8.92	9.06	31.8	25.0	18.7	9.7	31.8	28.5	25.3	21.6
		Method 2	8.37	8.59	8.78	8.96	9.12	19.1	15.4	12.6	8.4	19.1	17.3	15.8	14.0
		Method 3	8.37	8.57	8.73	8.85	8.95	23.2	19.8	16.8	12.1	23.2	21.6	20.1	18.3
System 5. Secondary rural															
1.	NE	Method 1	5.01	5.11	5.22	5.33	5.44	15.6	12.5	10.3	6.7	15.6	14.0	12.8	11.3
		Method 2	5.12	5.17	5.22	5.28	5.33	15.6	12.1	9.3	6.0	15.6	13.9	12.3	10.7
		Method 3	5.13	5.18	5.22	5.27	5.31	20.4	15.5	12.2	8.2	20.4	17.9	16.0	14.0
2.	MA	Method 1	5.01	5.11	5.22	5.33	5.44	13.2	10.4	8.8	5.6	13.2	11.8	10.8	9.5
		Method 2	5.12	5.17	5.22	5.28	5.33	13.3	10.0	7.6	5.1	13.3	11.7	10.3	9.0
		Method 3	5.13	5.18	5.22	5.27	5.31	17.0	13.2	9.9	7.0	17.0	15.1	13.3	11.8
3.	SAN	Method 1	4.76	4.86	4.98	5.10	5.22	7.6	5.6	4.4	2.8	7.6	6.6	5.8	5.0
		Method 2	4.80	4.86	4.92	4.97	5.01	6.5	5.6	5.0	3.5	6.5	6.1	5.8	5.3
		Method 3	4.82	4.86	4.90	4.94	4.98	10.1	8.4	6.9	4.4	10.1	9.3	8.5	7.4
4.	SAS	Method 1	4.56	4.66	4.77	4.89	5.00	6.9	5.3	4.1	2.7	6.9	6.1	5.4	4.7
		Method 2	4.60	4.66	4.71	4.76	4.80	5.7	5.0	4.2	3.0	5.7	5.4	5.0	4.6
		Method 3	4.62	4.66	4.70	4.74	4.77	8.4	7.1	5.6	3.8	8.4	7.8	7.0	6.2

Table 10-37.--Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 6 of 7

Census division and analysis method			Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
			18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 5. Secondary rural--continued															
5.	ENC	Method 1	5.17	5.30	5.41	5.52	5.61	5.4	4.8	3.8	2.2	5.4	5.1	4.7	4.2
		Method 2	5.17	5.31	5.43	5.52	5.60	3.7	3.4	3.5	2.4	3.7	3.5	3.5	3.3
		Method 3	5.17	5.27	5.36	5.43	5.49	5.7	5.4	5.3	3.6	5.7	5.6	5.5	5.1
6.	WNC	Method 1	5.04	5.17	5.28	5.38	5.47	4.9	4.2	3.4	1.9	4.9	4.5	4.2	3.7
		Method 2	5.04	5.18	5.29	5.39	5.46	3.2	3.1	3.1	2.1	3.2	3.2	3.1	2.9
		Method 3	5.04	5.14	5.23	5.29	5.35	5.1	4.7	4.8	3.2	5.1	4.9	4.9	4.6
7.	ESC	Method 1	5.17	5.30	5.41	5.52	5.61	4.2	3.5	2.8	1.6	4.2	3.8	3.5	3.1
		Method 2	5.17	5.31	5.43	5.52	5.60	2.8	2.5	2.5	1.7	2.8	2.7	2.7	2.5
		Method 3	5.17	5.27	5.36	5.43	5.49	4.2	3.7	3.6	2.4	4.2	4.0	3.9	3.6
8.	WSC	Method 1	5.17	5.30	5.41	5.52	5.61	5.8	5.0	4.1	2.3	5.8	5.4	5.0	4.4
		Method 2	5.17	5.31	5.43	5.52	5.60	3.9	3.6	3.8	2.7	3.9	3.8	3.8	3.6
		Method 3	5.17	5.27	5.36	5.43	5.49	6.1	5.5	5.6	3.8	6.1	5.8	5.7	5.4
9.	M	Method 1	4.88	5.00	5.11	5.21	5.30	6.5	5.5	4.6	2.6	6.5	6.0	5.6	4.9
		Method 2	4.88	5.02	5.13	5.22	5.29	4.4	3.9	4.2	2.9	4.4	4.2	4.2	3.9
		Method 3	4.88	4.98	5.06	5.13	5.18	6.8	6.2	6.4	4.4	6.8	6.5	6.5	6.1
10.	P	Method 1	4.95	5.07	5.19	5.29	5.38	5.8	4.9	4.0	2.3	5.8	5.4	5.0	4.4
		Method 2	4.95	5.09	5.20	5.29	5.37	3.9	3.6	3.6	2.4	3.9	3.7	3.7	3.5
		Method 3	4.95	5.05	5.13	5.20	5.26	6.0	5.5	5.4	3.6	6.0	5.7	5.6	5.3
System 6. Secondary urban															
1.	NE	Method 1	5.29	5.44	5.59	5.73	5.85	10.2	8.2	6.4	3.7	10.2	9.2	8.3	7.2
		Method 2	5.44	5.52	5.59	5.65	5.71	4.4	3.5	2.9	1.7	4.4	3.9	3.6	3.1
		Method 3	5.46	5.53	5.59	5.65	5.70	5.1	4.0	3.4	2.1	5.1	4.6	4.2	3.7
2.	MA	Method 1	5.56	5.69	5.83	5.95	6.07	8.4	6.6	5.3	2.7	8.4	7.5	6.8	5.8
		Method 2	5.69	5.76	5.83	5.89	5.94	4.6	3.6	2.9	1.8	4.6	4.1	3.7	3.2
		Method 3	5.71	5.77	5.83	5.88	5.92	5.3	4.2	3.4	2.2	5.3	4.7	4.3	3.8
3.	SAN	Method 1	6.05	6.24	6.41	6.55	6.67	6.0	5.3	4.2	2.4	6.0	5.6	5.2	4.5
		Method 2	6.16	6.24	6.32	6.39	6.45	6.0	4.7	3.8	2.3	6.0	5.3	4.8	4.2
		Method 3	6.18	6.24	6.30	6.36	6.41	7.1	5.6	4.6	2.9	7.1	6.3	5.8	5.1

Table 10-37.--Design rigid pavement slab depth and benefit-cost ratios for five levels of maximum axle-weight limits with transition, by highway system, census division, and analysis method

Sheet 7 of 7

Census division and analysis method			Design rigid pavement depth - inches					Incremental benefit-cost ratio				Overall benefit-cost ratio			
			18/32	20/35	22/38	24/41	26/44	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
System 6. Secondary urban--continued															
4.	SAS	Method 1	5.43	5.57	5.71	5.85	5.90	3.9	3.3	3.0	1.9	3.9	3.6	3.4	3.0
		Method 2	5.49	5.57	5.65	5.72	5.78	3.1	2.4	2.0	1.3	3.1	2.7	2.5	2.2
		Method 3	5.50	5.57	5.64	5.69	5.74	3.6	2.8	2.4	1.6	3.6	3.2	3.0	2.6
5.	ENC	Method 1	5.50	5.65	5.79	5.94	6.06	2.5	2.2	1.9	1.3	2.5	2.4	2.2	2.0
		Method 2	5.50	5.60	5.68	5.75	5.82	2.0	1.6	1.3	0.9	2.0	1.8	1.7	1.5
		Method 3	5.50	5.58	5.65	5.71	5.77	2.4	1.9	1.5	1.0	2.4	2.2	1.9	1.7
6.	WNC	Method 1	4.75	4.87	4.99	5.11	5.22	2.4	2.2	1.7	1.1	2.4	2.3	2.1	1.9
		Method 2	4.75	4.84	4.91	4.97	5.03	1.9	1.6	1.3	0.7	1.9	1.8	1.6	1.4
		Method 3	4.75	4.83	4.89	4.95	4.99	2.2	1.9	1.5	0.9	2.2	2.1	1.9	1.7
7.	ESC	Method 1	5.76	5.90	6.02	6.15	6.26	2.0	1.8	1.4	0.9	2.0	1.9	1.7	1.5
		Method 2	5.76	5.84	5.91	5.97	6.04	2.1	1.6	1.3	0.7	2.1	1.8	1.6	1.4
		Method 3	5.76	5.83	5.89	5.94	5.99	2.4	1.8	1.5	0.9	2.4	2.1	1.9	1.7
8.	WSC	Method 1	5.48	5.63	5.78	5.92	6.05	2.6	2.2	1.9	1.4	2.6	2.4	2.3	2.0
		Method 2	5.48	5.56	5.64	5.71	5.77	2.1	1.6	1.3	0.9	2.1	1.9	1.7	1.5
		Method 3	5.48	5.55	5.62	5.67	5.72	2.5	1.9	1.6	1.1	2.5	2.2	2.0	1.8
9.	M	Method 1	6.11	6.29	6.45	6.59	6.71	9.5	8.1	6.7	4.3	9.5	8.8	8.1	7.3
		Method 2	6.11	6.28	6.42	6.54	6.64	7.7	6.4	5.6	3.5	7.7	7.1	6.6	5.9
		Method 3	6.11	6.26	6.37	6.46	6.53	9.7	8.2	7.0	4.8	9.7	9.0	8.4	7.6
10.	P	Method 1	6.57	6.74	6.90	7.04	7.17	3.1	2.6	2.2	1.4	3.1	2.9	2.6	2.3
		Method 2	6.57	6.79	6.95	7.08	7.18	2.6	2.1	1.7	1.1	2.6	2.4	2.2	1.9
		Method 3	6.57	6.74	6.87	6.97	7.05	3.2	2.5	2.1	1.4	3.2	2.8	2.6	2.3

The effect of the transition period and of the increase in payload per vehicle is illustrated by the following benefit-cost ratios for highway systems 1 and 3, Interstate rural and primary rural, in the East North Central census division:

Analysis method	Single/tandem axle-weight limits, kips			
	18/32 to 20/35	20/35 to 22/38	22/38 to 24/41	24/41 to 26/44
Method 1				
Interstate rural				
with transition	13.6	11.9	10.5	8.0
without transition	13.5	12.5	11.8	11.2
Primary rural				
with transition	8.7	8.1	7.2	4.9
without transition	8.5	8.5	8.1	7.5
Methods 2 and 3 with transition				
Interstate rural				
with increase in payload	39.8	32.5	27.2	21.3
without increase in payload	57.8	46.7	39.6	32.0
Primary rural				
with increase in payload	17.1	14.4	12.4	8.0
without increase in payload	24.2	20.5	18.7	13.0

E. Rigid and Flexible Pavement Comparisons

All methods of analysis produce benefit-cost ratios that are generally higher for flexible than for rigid pavement. There is some shifting by census division and by highway system. The construction cost is generally higher for rigid than for flexible pavement, and since the motor vehicle operating costs are assumed to be the same for both types of pavement, it logically follows that the benefit-cost ratios would favor the flexible pavement. Table 10-38 gives the summary of the ratios for the New England and East North Central census divisions.

Because there is no pronounced difference in the final benefit-cost ratios, most of the summary tables and discussions pertain to rigid pavement. Rigid pavement is chosen because its single slab design offers a better basis of comparison of design depth than does flexible pavement with its three structural layers

F. Comparison of Methods 1 and 2 of Determining the Economy of Axle-Weight Limits

The two critical factors in the analysis of the economy of axle-weight maximum limits are the forecasts of the vehicle class distribution in the ADT and the axle-weight distribution for each vehicle class that would use the highways under conditions of higher legal axle-weight limits. To compare the results of the analysis by Methods 1 and 2 is in order.

Such factors as legal gross weight limits, legal vehicle length limits, legal restrictions on the number of cargo units per vehicle combination vehicle, and enforcement of the applicable laws lead to certain transport practices in each State. Types of commodities, terrain, length of haul, and other transport factors also influence the composition and weight of the vehicles in the ADT. Thus, from one State to another,

Table 10-38. -- Comparison of the benefit-cost ratios for rigid and flexible pavements for Method 1 with transition, New England and East North Central Census Divisions

Highway system and pavement type	Increment of increase in single/tandem axle weight limits, kips							
	18/32 to 20/35		20/35 to 22/38		22/38 to 24/41		24/41 to 26/44	
	New England	East North Central	New England	East North Central	New England	East North Central	New England	East North Central
1. Interstate rural								
Rigid	13.6	13.6	12.1	11.9	10.7	10.5	7.7	8.0
Flexible	14.1	11.8	12.4	10.7	10.8	9.7	7.7	7.6
2. Interstate urban								
Rigid	45.3	23.7	37.4	20.9	29.9	17.9	18.3	12.9
Flexible	49.6	23.6	40.0	20.8	31.3	17.8	18.8	12.8
3. Primary-rural								
Rigid	8.9	8.7	7.8	8.1	6.8	7.2	4.4	4.9
Flexible	9.8	8.1	8.3	7.2	7.1	6.1	4.5	4.0
4. Primary-urban								
Rigid	30.2	22.4	26.0	17.7	21.9	13.1	13.4	6.4
Flexible	29.9	21.0	26.0	16.7	21.9	12.2	13.4	6.0
5. Secondary-rural								
Rigid	15.6	5.4	12.5	4.8	10.3	3.8	6.7	2.2
Flexible	17.8	6.4	14.0	5.0	11.4	3.7	7.1	2.0
6. Secondary-urban								
Rigid	10.2	2.5	8.2	2.2	6.4	1.9	3.7	1.3
Flexible	10.6	2.6	8.4	2.2	6.6	1.9	3.8	1.3

there are factors other than the axle-weight limits that control the number of vehicles, the relative numbers of vehicles in each vehicle class, and the loading practice.

Method 1 does not take these factors into consideration. There is no known direct and positive way to do so. However, since there is ample evidence in the truck weight studies and in transport practice that motor freight carriers will utilize higher axle-weight limits whenever they are authorized, there is some basis for assuming that some of the traffic at lower axle-weight limits will move to higher axle weights when they become legal.

Both methods 1 and 2 retain the effects of loading beyond legal limits. Analysis of the 1962 truck weight study indicates that, generally, overloaded axles will prevail regardless of the maximum limits of legal axle weights.

Neither method considers the real possibility that if higher axle weights should be legally authorized, there is apt to be an increase in highway transport use. To a degree this factor is considered in the forecast to 1990 of a 29-percent increase in payload per vehicle and is reflected in some increase in the percentage of the total (all modes) of intercity freight movement to be handled by highway transport. It is not, however, of special importance in the present analysis. If increased axle-weight limits resulted in increased use of the highways, it would only increase the benefits above those computed without considering such an increase.

There is a current shift in the use of vehicles from the 2-S1 to the 2-S2 and from the 2-S2 to the 3-S2. Neither Method 1 nor 2 accounts for this change but assumes that the same vehicle class will carry the same total tons of payload as before. This assumption is a weakness in the methods, but is on the conservative side. A shift to heavier vehicles results in transport economy, even at the same axle-weight limits. Therefore, the economy as calculated by Methods 1 and 2 is less than is likely to be experienced.

Method 2 results in the same average payload weight and the same E 18-kip axles per vehicle for a given vehicle class for all census divisions. This result is distinctly different from Method 1, where the step up to the next axle-weight level was accomplished by adjusting the 1962 axle-weight distribution separately for each census division. But Method 2 uses a National ratio of average payload weight and E 18-kip axles to practical maximum gross vehicle weight, based on the values by States.

The 1962 truck weight study is not a perfect sample of transport highway use. However, from year to year this study has been consistent in its trends of transport practice. By using the data by census division rather than by States, many of the deficiencies of the sample are averaged out.

Neither Method 1 nor 2 considers the effects that vehicle limits in one State have on highway usage in other States. It is known that, Nationwide, vehicle weights and frequencies are held down in a liberal State by less liberal limits in nearby States.

From table 10-37 may be gained the correct impression that the benefit-cost ratio tends to increase as the traffic volume increases, but there are many exceptions when the comparisons are made between census divisions and highway systems.

If, for example, the economy of increasing from 18/32-kip to 20/35-kip limits were calculated for one census division and one highway system for a range of ADT, the results would be a consistent increase in economy with increases in ADT. The difference between this proposed calculation and the results in table 10-37 is that in table 10-37 the highway unit costs, highway total costs, the traffic mix, and highway designs (2 and 4 lanes) differ from system to system and from census division to census division. For instance, the cost of structures is not related to traffic volume, and this cost varies widely among highway systems and census divisions. The cost of paving is related to the ADT, because within the 20-year design period higher ADT's would apply a greater number of E 18-kip axles to to the pavement and thus require a thicker pavement. But this increase is not directly proportional to ADT and, further, it is obtained at a decreasing rate of increasing cost. The result is that it is correct logically to expect an increase in the economy of total costs of highway transport with increased ADT.

If all six highway systems and all ten census divisions are considered, the range in benefit-cost ratios in table 10-35 for analysis Method 1 is from 59.4 (System 4, ESC, 18/32 to 20/35 kips) to 0.9 (System 6, ESC, 24/41 to 26/44 kips). This ratio of 0.9 is the only one of the results using Method 1 that is less than 1.1. In fact, if Methods 1, 2, and 3 are all taken into account, only seven incremental B-C ratios (all at 24/41 to 26/44 kips) are less than 1.0 in a total of 720 ratios. In general, the incremental ratios are well above 2.0, indicating acceptable economy of highway transport for axle-weight limits up to a maximum of at least 26/44 kips.

From table 10-37 it will be observed that, for systems 1 and 3--the Interstate and primary rural systems--the B-C ratios are substantially less for Method 1 than for Method 2, but they are generally greater in the case of the two urban systems. For both secondary systems, the B-C ratios for Method 1 are, for the most part, slightly more than for Method 2.

In the Method 1 analysis, the axle-weight distributions from the 1962 truck weight study were calculated separately for each highway system and census division, except for some census divisions in systems 5 and 6. In the Method 2 calculations, curves for the relationships that the E 18-kip axles and average payload per vehicle bear to the practical maximum gross vehicle weight were the same for all six highway systems and for all ten census divisions. One result of the Method 2 procedure was that the slope of the curve of increasing E 18-kip axles against the five levels of axle-weight limits was less than the slope for Method 1 in those instances where the B-C ratio for Method 1 was greater than for Method 2. In other words, the less the E 18-kip axle applications increase with increases in axle-weight limits, the higher the B-C ratio.

15. COUNTERINTERACTING EFFECTS ON PAVEMENT CONSTRUCTION COST OF INCREASING THE NUMBER OF E 18-KIP AXLE APPLICATIONS

As would be expected, the results of pavement designs for each series of increases in maximum axle-weight limits produce increases in pavement depth and consequent increases in the cost of pavement construction. The increases in pavement construction cost with each imcrement of maximum axle-weight limit from 18/32 to 26/44 kips is a decreasing rate of increase rather than an increasing rate, as might be expected since the E 18-kip axle equivalents increase exponentially with increasing axle weight.

Figure 10-14 is a set of curves to illustrate two principal factors and their interaction. First, the top set of curves shows that the design depth of rigid pavement increases more rapidly at low than at high daily E 18-kip axle applications. Second, the middle curve shows in dollars per cubic yard the decreasing cost of the pavement as the depth increases. When

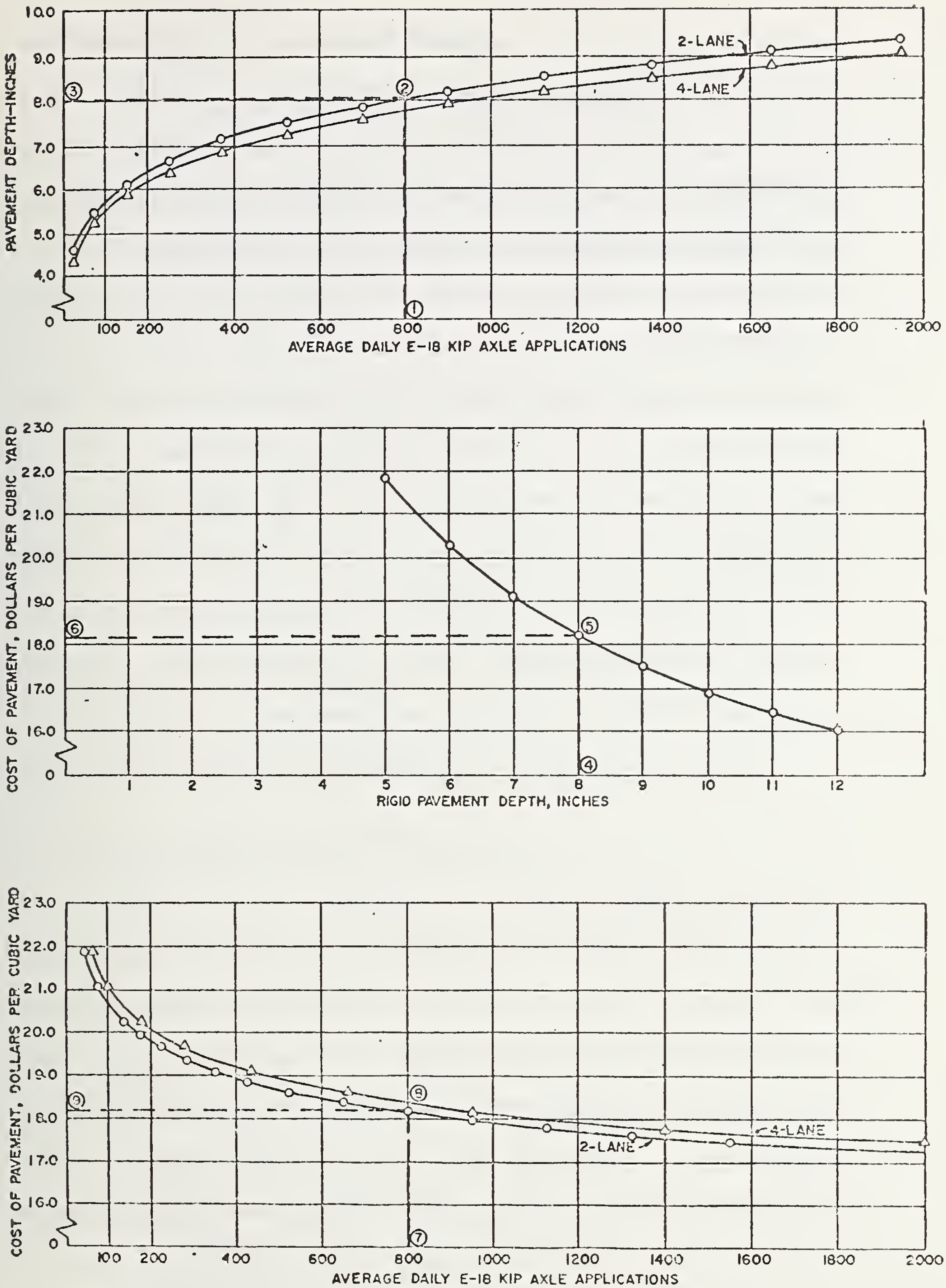

FIG. 10-14 CURVES TO SHOW THE INTERRELATIONSHIP OF E-18 KIP AXLE APPLICATIONS, RIGID PAVEMENT DESIGN DEPTH, AND COST OF PAVEMENT PER CUBIC YARD FOR HIGHWAY SYSTEM 3, PRIMARY RURAL, AND THE EAST NORTH CENTRAL CENSUS DIVISION.

these two factors--one a dampening increase in design depth and the other a dampening decrease in pavement cost per cubic yard--are combined, the result is a slightly decreasing rate of increase in pavement cost as the maximum axle-weight limits are increased from single/tandem limits of 18/32 kips to 26/44 kips.

CHAPTER 11

ECONOMY OF VEHICLE LENGTH - METHOD 4

In general, the greater the weight of payload per vehicle the less it costs in cents per ton-mile to transport cargo. Additional pounds of cargo per vehicle trip may be obtained in one of two ways: (1) by increasing the maximum limit of axle weight and increasing the gross vehicle weight limit accordingly or (2) by increasing the number of axles on the vehicle so that higher gross weight may be obtained without increasing the legal limit of axle weight. More axles per vehicle may be obtained by operating longer vehicles and combinations--more particularly by using two and three cargo units per vehicle combination. Thus, it is desirable to determine the economy of vehicle length in addition to determining the economy of axle-weight limit.

1. VEHICLE LENGTH AND ITS SIGNIFICANCE

Were it not for curvature on highways, street corners in urban areas, and ramps at interchanges, extremely long vehicles would be practical from the standpoint of highway design. On the other hand, the vehicle of a practical length for operation on the highway is restricted in its maneuverability at loading docks and at termini. Highways, both urban and rural, can accommodate vehicle combinations up to a limit of 65 or 70 feet without undue interference to other vehicles in the traffic stream and without too much offtracking on horizontal curves and ramps.

To obtain the 65- or 70-foot length by using a tractor-semitrailer with full trailer achieves the maximum maneuverability with a minimum of offtracking. The trailers in such a combination would be 27 to 30 feet in length. The combination with two or three cargo bodies provides another advantage to the transport industry in allowing the line-haul--or intercity haul--to be made with a longer combination vehicle. The trailers can be used separately in urban areas, and they may be simultaneously loaded and unloaded at the freight dock.

The advantage to the transport industry of two or three cargo bodies per combination is significant. But there is greater advantage with the 27-foot trailer than with the 40-foot trailer. The additional cube space of the 40-foot trailer is of no advantage to the trucker when cargo is being hauled that weighs more than about 20 pounds per cubic foot loaded and when the axle-weight limits are 18,000 and 32,000 pounds for single and tandem axles, respectively. Thus the haulers of light-density products are interested in more cargo space. The haulers of heavier-density cargo could get along satisfactorily using body lengths of less than 40 feet.

Vehicle length should not be considered separately from gross weight limits. The significance of the use of higher gross weights with the double-cargo combination is indicated by the fact that in 1963 about 15 States raised their gross weight limits to approximately 73,000 pounds, and in 1965 and 1966 eleven States increased their legal limits on length of combinations to 65 feet.

2. LIMITATIONS OF THE TRUCK WEIGHT STUDIES

The truck weight studies in a particular State are influenced not only by the law of that State but also by the laws of the surrounding States. A State permitting longer vehicles than do the surrounding States will not have the maximum use of the longer combination vehicle, because the interstate heavy truck traffic is governed by the minimum legal limits of either weight or dimension existing in the States where a vehicle on a specific trip is to travel.

It is to be remembered when examining the results of analysis of the economy of vehicle length that these results are prepared on the basis that there is no legal limit on gross vehicle weight. This is an important assumption, and its importance might be illustrated by considering the States in the West.

Several western States permit a gross weight of 76,000 pounds. They also permit 65-foot double-cargo combinations. On the other hand, the double-cargo combination is not used as extensively in the West as it would be if the gross vehicle weight limit were higher than 76,000 pounds. The reason for this is that with the 3-S2 tractor-semitrailer and an 18,000/32,000-pound axle-weight limit, the vehicle loaded to axle-weight capacity will weigh about 73,000 pounds gross. Therefore, the double-cargo combination is not of much advantage, particularly in hauling high-density products, because it could add only 3,000 pounds gross above the maximum for the 3-S2. The extra tare weight on the double-cargo combination would take up more than the 3,000-pound gross weight advantage gained. Therefore, in the western States, no payload advantage could come about by use of the double-cargo combination except when additional cubage is desired and when terminal functions are favorable.

3. PROCEDURE USED IN METHOD 4--ECONOMY OF VEHICLE LENGTH

The analysis of economy of the maximum length of vehicles and combinations may be made by setting up different fleets (mixes of various class of vehicles), each fleet being restricted by different maximum length of single-unit trucks, trailers, and trailer combinations. Each different fleet is assigned to haul the same total tons of payload for a unit of distance, say one mile. This approach was used in Method 4.

A. Selection of Length Limits

Five fleets were considered according to the length limits of individual vehicles and of vehicle combinations given in table 11-1. The selection of the length limits of the various vehicles was somewhat arbitrary. The lengths, however, are based upon what is practical, what the logical next steps in vehicular

Table 11-1. -- Combinations of vehicle lengths used in Method 4, Analysis of the Economy of Vehicle Length.

Step number	Identification		Vehicle maximum length, feet				
	Computer index no.	Table headings / Length limits [a]	Trailer	Single unit truck (2D, 3A)	Tractor with semitrailer (2-S1, 2-S2, 3-S2)	Tractive truck and full trailer (2-3, 3-4)	Tractor with semi and full trailer (2-S1-2, 2-S2-3 3-S2-4)
0	18	1962 law	←	——	——→	1962 law	
1	20	35/50 55/65	27 to 40	35	50	55	65
2	22	35/55 60/65	27 to 40	35	55	60	65
3	24	40/55 65/65	27 to 40	40	55	65	65
4	26	40/55 70/70	27 to 40	40	55	70	70

a/ First length (35 feet) applies to single unit trucks; second length (50 feet) applies to tractor with semitrailer; third length (55 feet) applies to a tractive truck with full trailer; and fourth length (65 feet) applies to a tractor with semitrailer and full trailer.

design would be from the standpoint of transport practice, and what the present law is.

B. Assignment of Payload Total Weight to Vehicle Classes

The assignment of pounds of payload to each vehicle class was done on the basis of the 1962 and 1963 truck weight studies--the data used in Method 1 on analysis of the economy of axle weights--and by judgment, applied to the State laws which affected the observed data in the truck weight studies. The average payload per vehicle for all trips (including empty cargo bodies), tare weights, and average gross vehicle weights are given in table 11-2 for the East North Central Census Division and the primary rural highway system.

Vehicle and vehicle-combination empty weights used are those in tables 14-1, 14-2, and 14-3.

C. Assignment of Average Payload Per Vehicle Within a Fleet and Determining the ADT of Each Vehicle Class

The average pounds of payload per vehicle, including empty vehicles, was established for each vehicle class by reference to the 1962 and 1963 truck weight data for each census division and highway system. See table 11-2 for these weights.

The number of vehicles in each vehicle class in the daily traffic stream and the average pounds of payload per vehicle were each determined in two steps. First, the vehicle classes were

Table 11-2.--Average payload, empty, and gross weights of each class of vehicle in Method 4
East North Central--primary, rural

Vehicle class	Weight, pounds	Method 4 (year 1962)				Method 4 (year 1990)			
		Step 1 35/50 55/65	Step 2 35/55 60/65	Step 3 40/55 65/65	Step 4 40/55 70/70	Step 1 35/50 55/65	Step 2 35/55 60/65	Step 3 40/55 65/65	Step 4 40/55 70/70
2D	Payload	4,235	4,235	4,837	4,837	4,235	4,235	4,837	4,837
	Empty weight	9,220	9,220	9,895	9,895	9,220	9,220	9,895	9,895
	Gross weight	13,455	13,455	14,732	14,732	13,455	13,455	14,732	14,732
3A	Payload	9,227	9,227	10,518	10,518	11,903	11,903	13,619	13,619
	Empty weight	15,635	15,635	16,585	16,585	15,635	15,635	16,585	16,585
	Gross weight	24,862	24,862	27,103	27,103	27,538	27,538	20,204	30,204
2-S1	Payload	6,064	6,667	6,667	6,667	7,823	8,610	8,610	8,610
	Empty weight	18,950	19,625	19,625	19,625	18,950	19,625	19,625	19,625
	Gross weight	25,014	26,292	26,292	26,292	26,773	28,235	28,235	28,235
2-S2	Payload	13,659	15,072	15,072	15,072	17,620	19,471	19,471	19,471
	Empty weight	23,550	24,500	24,500	24,500	23,550	24,500	24,500	24,500
	Gross weight	37,209	39,572	39,572	39,572	41,170	43,971	43,971	43,971
3-S2	Payload	13,659	23,099	23,099	23,099	27,093	29,804	29,804	29,804
	Empty weight	28,190	29,140	29,140	29,140	28,190	29,140	29,140	29,140
	Gross weight	49,192	52,239	52,239	52,239	55,283	58,944	58,944	58,944
3-2	Payload	22,542	24,581	26,625	28,688	29.079	31,717	34,368	36,984
	Empty weight	26,000	26,675	27,350	28,025	26,000	26,675	27,350	28,025
	Gross weight	48,542	51,256	52,975	56,713	55,079	58,392	61,718	65,009
3-4	Payload	27,575	29,989	32,575	34,988	35,572	38,739	41,914	45,053
	Empty weight	31,300	32,250	33,200	34,150	31,300	32,250	33,200	34,150
	Gross weight	58,375	62,239	65,775	69,138	66,872	70,989	75,114	79,203
2-S1-2	Payload	21,575	21,575	21,575	23,230	27,832	27,832	27,832	29,985
	Empty weight	28,500	28,500	28,500	29,040	28,500	28,500	28,500	29,040
	Gross weight	50,075	50,075	50,075	52,270	56,332	56,332	56,332	59,025
2-S2-3	Payload	27,541	27,541	27,541	29,721	35,528	35,528	35,528	38,154
	Empty weight	35,400	35,400	35,400	36,160	35,400	35,400	35,400	36,160
	Gross weight	62,941	62,941	62,941	65,881	70,928	70,928	70,928	74,314
3-S2-4	Payload	31,997	31,997	31,997	34,380	41,276	41,276	41,276	44,314
	Empty weight	40,400	40,400	40,400	41,160	40,400	40,400	40,400	41,160
	Gross weight	72,397	72,397	72,397	75,540	81,676	81,676	81,676	85,474

arrayed by increasing practical maximum gross vehicle weight. For each census division and each highway system, the percentage of each vehicle class in the truck ADT from 1962 truck weight study for combinations from the 2-S1 upward was plotted as a cumulative curve against the vehicle class shown in figure 11-1 for the primary rural highway system (System 3).

Because of the different legal limits in the ten census divisions, this plotting results in the family of curves in figure 11-1. The lowest solid curve represents the Pacific census division where the limit for combinations is 65 feet. The heavy dashed curve below the Pacific curve represents an estimate of the percentage distribution to be expected in all census divisions if all adopted the 65-foot maximum limit for two-cargo combinations.

The next step was to accumulate the pounds of payload per vehicle for each class from the 2-S1 upward and then to convert the pounds to the percentage of the total pounds carried by the total ADT.

Figure 11-2 is the result of this calculation. By using figures 11-1 and 11-2 in combination, first the percentage of the total ADT represented by a given class of vehicle is read from figure 11-1, and then the percentage of the total payload transported by this class of vehicle is read from figure 11-2.

The total pounds of payload to be transported by the ADT for each highway system and each census division is the same for

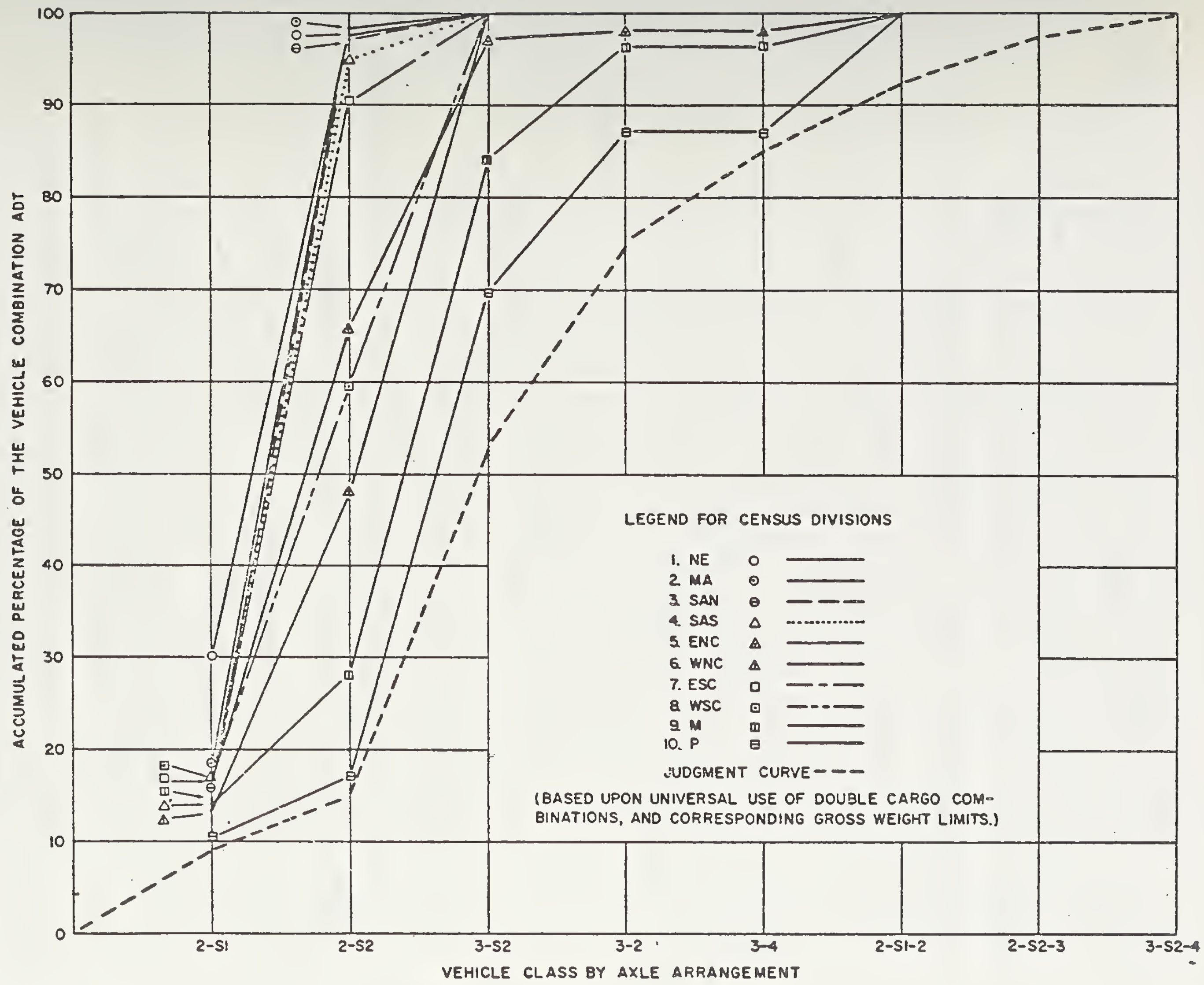

FIG. 11-1 ACCUMULATED PERCENTAGE OF THE ADT OF VEHICLE COMBINATIONS BASED UPON INCREASING PRACTICAL GROSS VEHICLE WEIGHTS OF 2-SI AND LARGER CLASSES OF COMBINATIONS; HIGHWAY SYSTEM 3, PRIMARY RURAL, BASED ON 1962 TRUCK WEIGHT STUDY.

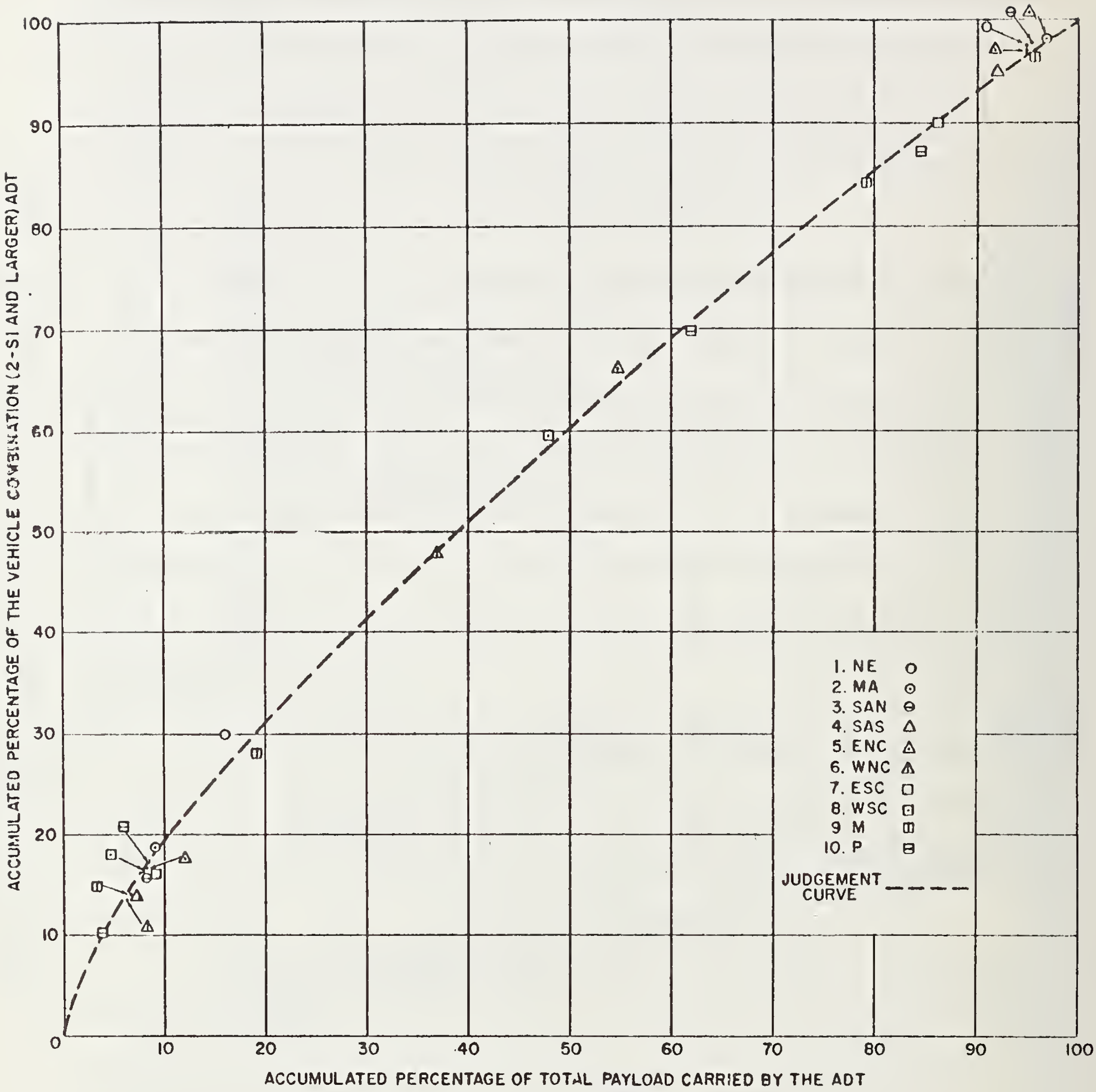

FIG. 11-2 ACCUMULATED PERCENTAGE OF THE ADT OF VEHICLE COMBINATIONS ARRANGED BY INCREASING PRACTICAL MAXIMUM GROSS WEIGHTS, VS. THE ACCUMULATED PERCENTAGE OF TOTAL PAYLOAD CARRIED BY THE ADT.

Method 4 as for Method 1. This total poundage multiplied by the percentage to be carried by a specific class of vehicle gives the total pounds to be transported by that class of vehicle. This figure divided by the average pounds per vehicle gives the number of vehicles of that class to be found in the total ADT.

Because the 2D and 3A single-unit trucks were considered to be unaffected by the changes in length of vehicle combinations, the same payload per vehicle and the same percentage of the total payload hauled by the ADT was assigned to these trucks. However, for steps 3 and 4, in which a 40-foot maximum length of single-unit truck is included, additional payload per vehicle was assigned to the 2D and 3A trucks over that assigned for the 35-foot maximum length.

D. Determining Number of E 18-kip Axle Applications

The E 18-kip axles for each class of vehicle for both rigid and flexible pavements were determined by reference to the results of Method 1. The average gross weight per vehicle by class for each highway system and census division was obtained by adding together the average tare weight and the average payload weight. Because of the different axle-weight and gross weight limits, there resulted ranges of average gross vehicle weights and corresponding E 18-kip axles per vehicle. See figure 11-3 for a plot of the curves for three vehicle classes.

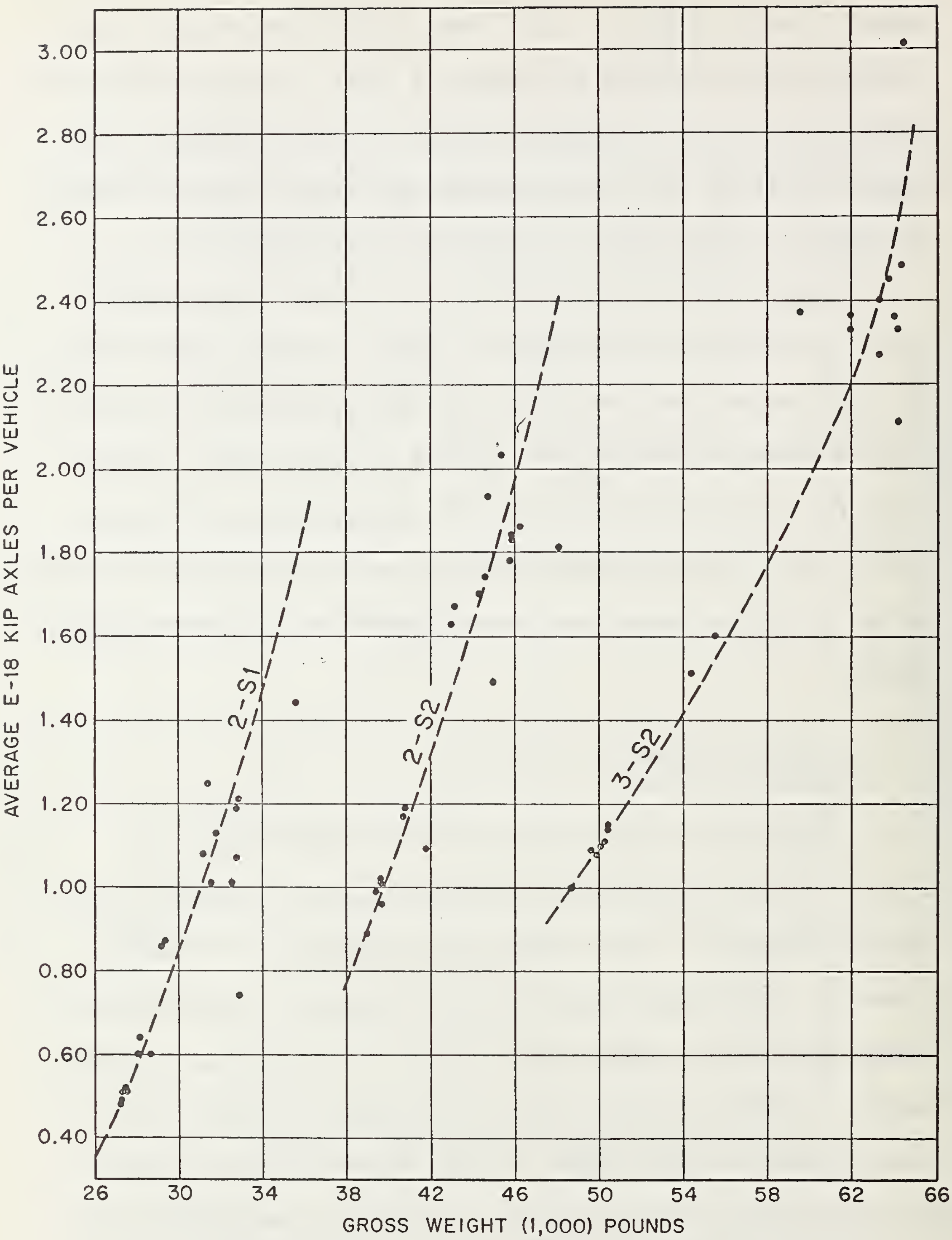

FIGURE 11-3.- SAMPLE SET OF CURVES FOR THE PRIMARY RURAL SYSTEM TO ILLUSTRATE HOW THE NUMBER OF E-18 KIP AXLES PER VEHICLE BY VEHICLE CLASS WAS DETERMINED FROM PLOTTING THE DATA OF METHOD 1 FOR TWO AXLE WEIGHT LIMITS FOR EACH CENSUS DIVISION

4. RESULTS OF THE ANALYSIS BY METHOD 4

Three sets of tables are presented to show the results of the analysis of vehicle length. Table 11-3 gives the number of vehicles in the ADT, 1962 and 1990, for each step increase in vehicle and combination length for system 3, census divisions 5 and 6. On a National basis, table 11-4N gives for each highway system the highway cost and motor vehicle operating costs for each step increase in vehicle and combination length for the 20-year period from 1965 through 1984 and the increments of change between increases in length step.

The analysis of the data proceeded as in Methods 1 through 4 with the expectation that the end point would be a benefit-cost ratio. But as the calculations shown in table 11-4N were made, it became evident that for many road systems in many census divisions, the construction costs decreased instead of increased with increased vehicle length. With a negative increment of investment outlay, the benefit-cost ratio would have no significance. The economy of increments of vehicle length must then be made by comparison of equivalent uniform annual costs. Table 11-4N shows only the change in highway cost, the decrease in motor vehicle operating costs, and the sum of these two changes.

Table 11-6 (National basis) gives the ratio of the costs computed in Method 4 for steps 1, 2, 3, and 4 to the costs under the 1962 laws for the following factors at each of the four added vehicle length limits:

Table 11-3.--Number of each class of vehicle in the ADT for 1962 and 1990, by highway system and census division used in analyzing the economy of vehicle length

Vehicle length step, feet	PASS CARS	BUSES	PANEL AND PICKUP	2S	2D	3A	2S1	2S2	3S2	C5	2T5	C7	2T7	2T9	SUB TOTAL	GRAND TOTAL
							System 1									
							CENSUS DIVISION 5									
1962																
1962 LAW	2596.0	9.0	143.0	35.0	142.0	22.0	46.0	135.0	85.0	3.0	5.0	.0	.0	.0	438.0	3221.0
35/50/55/65	2596.0	9.0	143.0	35.0	142.0	22.0	26.1	12.2	76.8	52.6	21.1	20.6	12.0	5.4	390.8	3173.8
35/55/60/65	2596.0	9.0	143.0	35.0	142.0	22.0	23.7	11.1	69.8	48.2	21.1	18.9	12.0	5.4	374.2	3157.2
40/55/65/65	2596.0	9.0	143.0	35.0	124.3	19.3	23.7	11.1	69.8	44.5	21.1	17.4	12.0	5.4	348.6	3131.6
40/55/70/70	2596.0	9.0	143.0	35.0	124.3	19.3	23.7	11.1	69.8	41.3	19.6	16.2	11.1	5.0	341.4	3124.4
1990																
1962 LAW	3211.0	7.0	198.0	49.0	148.0	27.0	40.0	180.0	136.0	4.0	6.0	.0	.0	.0	541.0	4006.0
35/50/55/65	3211.0	7.0	198.0	49.0	148.0	27.0	36.4	17.1	107.4	73.5	29.5	28.8	16.8	7.5	492.0	3957.0
35/55/60/65	3211.0	7.0	198.0	49.0	148.0	27.0	33.1	15.5	97.6	67.4	29.5	26.4	16.8	7.5	468.8	3933.8
40/55/65/65	3211.0	7.0	198.0	49.0	129.5	23.6	33.1	15.5	97.6	62.2	29.5	24.4	16.8	7.5	439.7	3904.7
40/55/70/70	3211.0	7.0	198.0	49.0	129.5	23.6	33.1	15.5	97.6	57.8	27.4	22.7	15.6	7.0	429.8	3894.8
							CENSUS DIVISION 6									
1962																
1962 LAW	1273.0	5.0	95.0	14.0	65.0	15.0	13.0	33.0	50.0	.0	.0	.0	.0	.0	176.0	1563.0
35/50/55/65	1273.0	5.0	95.0	14.0	65.0	15.0	9.7	4.6	28.6	19.6	7.8	7.6	4.5	2.0	164.4	1551.4
35/55/60/65	1273.0	5.0	95.0	14.0	65.0	15.0	8.8	4.2	26.0	18.0	7.8	7.0	4.5	2.0	158.3	1545.3
40/55/65/65	1273.0	5.0	95.0	14.0	56.9	13.1	8.8	4.2	26.0	16.6	7.8	6.5	4.5	2.0	146.4	1533.4
40/55/70/70	1273.0	5.0	95.0	14.0	56.9	13.1	8.8	4.2	26.0	15.4	7.2	6.0	4.2	1.9	143.7	1530.7
1990																
1962 LAW	1466.0	4.0	123.0	18.0	63.0	17.0	10.0	41.0	73.0	.0	.0	.0	.0	.0	204.0	1815.0
35/50/55/65	1466.0	4.0	123.0	18.0	63.0	17.0	13.1	6.1	38.5	26.4	10.6	10.3	6.0	2.7	193.7	1804.7
35/55/60/65	1466.0	4.0	123.0	18.0	63.0	17.0	11.9	5.5	35.0	24.2	10.6	9.4	6.0	2.7	185.3	1796.3
40/55/65/65	1466.0	4.0	123.0	18.0	55.1	14.9	11.9	5.5	35.0	22.3	10.6	8.7	6.0	2.7	172.7	1783.7
40/55/70/70	1466.0	4.0	123.0	18.0	55.1	14.9	11.9	5.5	35.0	20.7	9.8	8.1	5.6	2.5	169.1	1780.1

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Table 11-4N.- Comparison of highway cost and motor vehicle operating cost for five levels of maximum length of vehicles and combinations, for the 20-year period 1965 through 1984--National average

Highway System 1. IR   Method of Analysis 4 with transition   Census Division All

Cost Item	Rigid Pavement					Flexible Pavement				
	Maximum length of vehicles & combinations - feet 1/					Maximum length of vehicles & combinations - feet 1/				
	1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70	1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile: a. Pavement and shoulders	$213,097	$208,979	$210,287	$211,784	$212,518	$179,164	$175,116	$176,610	$178,394	$179,456
b. Bridge structures	200,634	200,634	200,634	200,634	200,634	200,634	200,634	200,634	200,634	200,634
c. Earthwork and drainage	190,465	190,316	190,357	190,403	190,426	190,465	190,063	190,191	190,342	190,429
d. Total construction cost	604,196	599,929	601,278	602,821	603,578	570,263	565,813	567,435	569,370	570,519
2. Equivalent uniform annual capital cost *	52,677	52,305	52,422	52,557	52,623	49,718	49,330	49,472	49,641	49,741
3. Incremental annual cost a. Capital cost	–	-372	+117	+135	+66	–	-388	+142	+169	+100
b. Maintenance cost of pavement and shoulders	–	-20	+7	+8	+4	–	-15	+6	+7	+4
c. Maintenance cost of structures	–	0	0	0	0	–	0	0	0	0
d. Total equivalent uniform annual highway cost	–	-392	+124	+143	+70	–	-403	+148	+176	+104
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by length limits: a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	231,907	207,504	199,528	190,946	188,497	231,907	207,504	199,528	190,946	188,497
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	-24,403	-7,976	-8,582	-2,449	–	-24,403	-7,976	-8,582	-2,449
INCREMENTAL CHANGE IN COMBINED TOTAL ANNUAL MOTOR TRUCK OPERATING COST PLUS ANNUAL HIGHWAY COST										
6. Incremental change in combined annual motor truck cost plus annual highway cost-dollars	–	-24,795	-7,852	-8,439	-2,379	–	-24,806	-7,828	-8,406	-2,345

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 11-4K- Comparison of highway cost and motor vehicle operating cost for five levels of maximum length of vehicles and combinations, for the 20-year period 1965 through 1984 --National average

Highway System 2. IU | Method of Analysis 4 with transition | Census Division All

Cost Item	Rigid Pavement: Maximum length of vehicles & combinations - feet1/ 1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70	Flexible Pavement: Maximum length of vehicles & combinations - feet1/ 1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile: a. Pavement and shoulders	$ 216,496	$ 214,963	$ 215,841	$ 217,563	$ 218,651	$ 182,796	$ 181,381	$ 182,548	$ 184,824	$ 185,416
b. Bridge structures	1,294,314	1,294,314	1,294,314	1,294,314	1,294,314	1,294,314	1,294,314	1,294,314	1,294,314	1,294,314
c. Earthwork and drainage	492,871	492,813	492,841	492,874	492,910	492,871	492,728	492,830	493,024	493,074
d. Total construction cost	2,003,681	2,002,070	2,002,996	2,004,771	2,005,275	1,969,981	1,968,423	1,969,692	1,972,162	1,972,804
2. Equivalent uniform annual capital cost *	174,691	174,552	174,631	174,786	174,830	171,753	171,617	171,728	171,943	171,999
3. Incremental annual cost a. Capital cost	–	-139	+79	+155	+44	–	-136	+111	+215	+56
b. Maintenance cost of pavement and shoulders	–	-10	+7	+13	+4	–	-6	+7	+13	+3
c. Maintenance cost of structures	–	0	0	0	0	–	0	0	0	0
d. Total equivalent uniform annual highway cost	–	-149	+86	+168	+48	–	-142	+118	+228	+59
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by length limits: a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	366,271	333,022	325,784	299,718	299,102	366,271	333,022	325,784	299,718	299,102
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	-33,249	-7,238	-26,066	-616	–	-33,249	-7,238	-26,066	-616
INCREMENTAL CHANGE IN COMBINED TOTAL ANNUAL MOTOR TRUCK OPERATING COST PLUS ANNUAL HIGHWAY COST										
6. Incremental change in combined annual motor truck cost plus annual highway cost-dollars	–	-33,398	-7,152	-25,898	-568	–	-33,391	-7,120	-25,838	-557

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table II-4 N.- Comparison of highway cost and motor vehicle operating cost for five levels of maximum length of vehicles and combinations, for the 20-year period 1965 through 1984 --National average

Highway System 3. PR Method of Analysis 4 with transition Census Division All

Cost Item	Rigid Pavement: Maximum length of vehicles & combinations - feet 1/ 1962 law	35/50/ 55/65	35/55/ 60/65	40/55/ 65/65	40/55/ 70/70	Flexible Pavement: Maximum length of vehicles & combinations - feet 1/ 1962 law	35/50/ 55/65	35/55/ 60/65	40/55/ 65/65	40/55/ 70/70
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile: a. Pavement and shoulders	$156,503	$153,458	$154,548	$155,494	$156,658	$131,142	$127,602	$128,772	$131,096	$131,979
b. Bridge structures	31,194	31,194	31,194	31,194	31,194	31,194	31,194	31,194	31,194	31,194
c. Earthwork and drainage	86,710	86,606	86,641	86,687	86,710	86,710	86,382	86,483	86,684	86,759
d. Total construction cost	274,407	271,258	272,383	273,830	274,562	249,046	245,178	246,449	248,974	249,932
2. Equivalent uniform annual capital cost *	23,924	23,650	23,748	23,874	23,938	21,713	21,376	21,487	21,707	21,790
3. Incremental annual cost a. Capital cost	—	-274	+98	+126	+64	—	-337	+111	+220	+83
b. Maintenance cost of pavement and shoulders	—	-15	+6	+7	+3	—	-12	+4	+8	+3
c. Maintenance cost of structures	—	0	0	0	0	—	0	0	0	0
d. Total equivalent uniform annual highway cost	—	-289	+104	+133	+67	—	-349	+115	+228	+86
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by length limits: a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	55,973	50,705	49,064	46,478	46,438	55,973	50,705	49,064	46,478	46,438
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	-5,268	-1,641	-2,586	-40	—	-5,268	-1,641	-2,586	-40
INCREMENTAL CHANGE IN COMBINED TOTAL ANNUAL MOTOR TRUCK OPERATING COST PLUS ANNUAL HIGHWAY COST										
6. Incremental change in combined annual motor truck cost plus annual highway cost-dollars	—	-5,557	-1,537	-2,453	+27	—	-5,617	-1,526	-2,358	+46

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 11-4N.- Comparison of highway cost and motor vehicle operating cost for five levels of maximum length of vehicles and combinations, for the 20-year period 1965 through 1984--National average

Highway System 4. PU　　Method of Analysis 4 with transition　　Census Division All

Cost Item	Rigid Pavement: Maximum length of vehicles & combinations - feet 1/ 1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70	Flexible Pavement: Maximum length of vehicles & combinations - feet 1/ 1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile: a. Pavement and shoulders	$161,496	$160,006	$160,767	$164,074	$164,473	$136,081	$134,103	$134,923	$139,208	$139,668
b. Bridge structures	119,813	119,813	119,813	119,813	119,813	119,813	119,813	119,813	119,813	119,813
c. Earthwork and drainage	173,963	173,905	173,932	174,043	174,057	173,963	173,776	173,846	174,232	174,273
d. Total construction cost	455,272	453,724	454,512	457,930	458,343	429,857	427,692	428,582	433,253	433,754
2. Equivalent uniform annual capital cost *	39,693	39,558	39,627	39,925	39,961	37,477	37,288	37,366	37,773	37,817
3. Incremental annual cost a. Capital cost	–	-135	+69	+298	+36	–	-189	+78	+407	+44
b. Maintenance cost of pavement and shoulders	–	-11	+6	+23	+3	–	-9	+4	+22	+2
c. Maintenance cost of structures	–	0	0	0	0	–	0	0	0	0
d. Total equivalent uniform annual highway cost	–	-146	+75	+321	+39	–	-198	+82	+429	+46
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by length limits: a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	134,415	117,984	115,938	106,791	107,454	134,415	117,984	115,938	106,791	107,454
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	-16,431	-2,046	-9,147	+663	–	-16,431	-2,046	-9,147	+663
INCREMENTAL CHANGE IN COMBINED TOTAL ANNUAL MOTOR TRUCK OPERATING COST PLUS ANNUAL HIGHWAY COST										
6. Incremental change in combined annual motor truck cost plus annual highway cost-dollars	–	-16,577	-1,971	-8,826	+702	–	-16,629	-1,964	-8,718	+709

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 11-4N.- Comparison of highway cost and motor vehicle operating cost for five levels of maximum length of vehicles and combinations, for the 20-year period 1965 through 1984 --National average

Highway System 5. SR   Method of Analysis 4 with transition   Census Division All

Cost Item	Rigid Pavement: Maximum length of vehicles & combinations - feet1/ 1962 law	35/50/ 55/65	35/55/ 60/65	40/55/ 65/65	40/55/ 70/70	Flexible Pavement: Maximum length of vehicles & combinations - feet1/ 1962 law	35/50/ 55/65	35/55/ 60/65	40/55/ 65/65	40/55/ 70/70
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile: a. Pavement and shoulders	$84,352	$83,331	$83,637	$84,741	$84,839	$68,808	$67,793	$68,067	$69,238	$69,328
b. Bridge structures	9,244	9,244	9,244	9,244	9,244	9,244	9,244	9,244	9,244	9,244
c. Earthwork and drainage	34,250	34,216	34,225	34,260	34,262	34,250	34,166	34,186	34,285	34,292
d. Total construction cost	127,846	126,791	127,106	128,245	128,345	112,302	111,203	111,497	112,767	112,864
2. Equivalent uniform annual capital cost *	11,146	11,054	11,082	11,181	11,190	9,791	9,695	9,721	9,832	9,840
3. Incremental annual cost a. Capital cost	-	-92	+28	+99	+9	-	-96	+26	+111	+8
b. Maintenance cost of pavement and shoulders	-	-3	+1	+3	0	-	-2	0	+2	0
c. Maintenance cost of structures	-	0	0	0	0	-	0	0	0	0
d. Total equivalent uniform annual highway cost	-	-95	+29	+102	+9	-	-98	+26	+113	+8
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by length limits: a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	10,051	10,114	9,876	9,105	9,105	10,051	10,114	9,876	9,105	9,105
5. Incremental equivalent uniform decrements in annual vehicle operating cost	-	+63	-238	-771	0	-	+63	-238	-771	0
INCREMENTAL CHANGE IN COMBINED TOTAL ANNUAL MOTOR TRUCK OPERATING COST PLUS ANNUAL HIGHWAY COST										
6. Incremental change in combined annual motor truck cost plus annual highway cost-dollars	-	-32	-209	-669	+9	-	-35	-212	-658	+8

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 11-4N.- Comparison of highway cost and motor vehicle operating cost for five levels of maximum length of vehicles and combinations, for the 20-year period 1965 through 1984--National average

Highway System 6. SU   Method of Analysis 4 with transition   Census Division All

Cost Item	Rigid Pavement					Flexible Pavement				
	Maximum length of vehicles & combinations - feet 1/					Maximum length of vehicles & combinations - feet 1/				
	1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70	1962 law	35/50/55/65	35/55/60/65	40/55/65/65	40/55/70/70
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile: a. Pavement and shoulders	$88,982	$87,837	$88,179	$89,015	$89,153	$72,930	$71,712	$72,093	$73,147	$73,327
b. Bridge structures	40,814	40,814	40,814	40,814	40,814	40,814	40,814	40,814	40,814	40,814
c. Earthwork and drainage	49,078	49,030	49,051	49,078	49,082	49,078	48,973	49,004	49,094	49,109
d. Total construction cost	178,874	177,681	178,044	178,907	179,049	162,822	161,499	161,911	163,055	163,250
2. Equivalent uniform annual capital cost *	15,595	15,491	15,523	15,598	15,610	14,196	14,080	14,116	14,216	14,233
3. Incremental annual cost a. Capital cost	—	-104	+32	+75	+12	—	-116	+36	+100	+17
b. Maintenance cost of pavement and shoulders	—	-5	+1	+4	+1	—	-3	+1	+3	+1
c. Maintenance cost of structures	—	0	0	0	0	—	0	0	0	0
d. Total equivalent uniform annual highway cost	—	-109	+33	+79	+13	—	-119	+37	+103	+18
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by length limits: a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	28,999	26,913	26,436	24,264	24,395	28,999	26,913	26,436	24,264	24,395
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	-2,086	-477	-2,172	+131	—	-2,086	-477	-2,172	+131
INCREMENTAL CHANGE IN COMBINED TOTAL ANNUAL MOTOR TRUCK OPERATING COST PLUS ANNUAL HIGHWAY COST										
6. Incremental change in combined annual motor truck cost plus annual highway cost-dollars	—	-2,195	-444	-2,093	+144	—	-2,205	-440	-2,069	+149

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

Table 11-6. -- National averages for Method 4, economy of vehicle length - rigid pavement

	Step 0	Step 1	Step 2	Step 3	Step 4	Ratio to Step 0				
						Step 0	Step 1	Step 2	Step 3	Step 4
1. Interstate rural										
EUAHC, $	55,822	55,430	55,555	55,697	55,767	1.000	0.993	0.995	0.998	0.999
EUAMVOC, $	231,907	207,504	199,528	190,946	188,497	1.000	0.895	0.860	0.823	0.813
EUAHC + EUAMVOC, $	287,729	262,934	255,083	246,643	244,264	1.000	0.914	0.886	0.857	0.849
Hwy. constr. cost, $	604,196	599,929	601,278	602,821	603,578	1.000	0.993	0.995	0.998	0.999
1962 ADT	1,035	844	807	756	733	1.000	0.815	0.780	0.730	0.708
2. Interstate urban										
EUAHC, $	180,060	179,912	179,997	180,165	180,213	1.000	0.999	0.999	1.000	1.001
EUAMVOC, $	366,271	333,022	325,784	299,718	299,102	1.000	0.909	0.889	0.818	0.817
EUAHC + EUAMVOC, $	546,331	512,934	505,781	479,883	479,315	1.000	0.939	0.926	0.878	0.877
Hwy. constr. cost, $	2,003,681	2,002,090	2,002,996	2,004,771	2,005,275	1.000	0.999	0.999	1.000	1.001
1962 ADT	1,466	1,288	1,261	1,136	1,121	1.000	0.879	0.860	0.775	0.765
3. Primary rural										
EUAHC, $	25,905	25,615	25,719	25,852	25,919	1.000	0.989	0.993	0.998	1.001
EUAMVOC, $	55,973	50,705	49,064	46,478	46,438	1.000	0.906	0.877	0.830	0.830
EUAHC + EUAMVOC, $	81,878	76,320	74,783	72,330	72,357	1.000	0.932	0.913	0.883	0.884
Hwy. constr. cost, $	274,407	271,258	272,383	273,830	274,562	1.000	0.988	0.993	0.998	1.001
1962 ADT	364	312	301	279	273	1.000	0.857	0.827	0.766	0.750
4. Primary urban										
EUAHC, $	43,008	42,863	42,937	43,258	43,297	1.000	0.997	0.998	1.006	1.007
EUAMVOC, $	134,415	117,984	115,938	106,791	107,454	1.000	0.878	0.862	0.794	0.799
EUAHC + EUAMVOC, $	177,423	160,847	158,875	150,049	150,751	1.000	0.907	0.895	0.846	0.850
Hwy. constr. cost, $	455,272	453,724	454,512	457,930	458,343	1.000	0.996	0.998	1.006	1.007
1962 ADT	803	689	675	607	600	1.000	0.858	0.841	0.756	0.747

Table 11-6. -- National averages for Method 4, economy of vehicle length - rigid pavement

	Step 0	Step 1	Step 2	Step 3	Step 4	Ratio to Step 0				
						Step 0	Step 1	Step 2	Step 3	Step 4
5. Secondary rural										
EUAHC, $	11,671	11,576	11,604	11,707	11,716	1.000	0.992	0.994	1.003	1.004
EUAMVOC, $	10,051	10,114	9,876	9,105	9,105	1.000	1.006	0.983	0.906	0.906
EUAHC + EUAMVOC, $	21,722	21,690	21,480	20,812	20,821	1.000	0.999	0.989	0.958	0.959
Hwy. constr. cost, $	127,846	126,791	127,106	128,245	128,345	1.000	0.992	0.994	1.003	1.004
1962 ADT	64	62	61	55	54	1.000	0.969	0.953	0.859	0.844
6. Secondary urban										
EUAHC, $	16,557	16,449	16,482	16,561	16,574	1.000	0.993	0.995	1.000	1.001
EUAMVOC, $	28,999	26,913	26,436	24,264	24,395	1.000	0.928	0.912	0.837	0.841
EUAHC + EUAMVOC, $	45,556	43,362	42,918	40,825	40,969	1.000	0.952	0.942	0.896	0.899
Hwy. constr. cost, $	178,874	177,681	178,044	178,907	179,049	1.000	0.993	0.995	1.000	1.001
1962 ADT	197	178	174	157	155	1.000	0.904	0.883	0.797	0.787

EUAHC--Equivalent Uniform Annual Highway Cost.
EUAMVOC--Equivalent Uniform Annual Motor Vehicle Operating Cost.
Uniform costs calculated at 6 percent per year interest rate for 20 years 1965 through 1984.
Basis of Step 0 is the 1962 legal limits of length and axle weight.

(1) Equivalent uniform annual highway cost (EUAHC) for construction and maintenance.

(2) Equivalent uniform annual motor vehicle operating cost (EUAMVOC).

(3) The total of (1) and (2) (EUATC).

(4) Total construction cost for pavement and shoulders, bridge structures, and earthwork and drainage.

(5) 1962 daily number of trucks.

5. DISCUSSION OF RESULTS OF METHOD 4

An examination of tables 11-3 and 11-6 shows that the increase in the limits of vehicle length from the 1962 law results in a significant reduction in the truck ADT. The percentage reduction varies with the highway system and census division.

An examination of table 11-6 discloses that the vehicle length increases from the 1962 legal limits to the 35/50/55/65-foot limits (Step 1) result in decreases in highway construction costs of from $1,055 per mile (secondary rural system) to $4,267 (Interstate rural system). These decreases in construction cost result from a decrease in the E 18-kip axle applications. The use of longer vehicles and combinations having a greater number of axles results in heavier gross vehicle weights per vehicle combination but fewer vehicles in total (see table 11-3) to haul the same tons of cargo. Also, for the double-cargo combinations, there is a greater ratio of payload weight to tare weight than for two separate single-cargo vehicles having a combined cargo cubic capacity equal to that of the double-cargo-body combination.

Perhaps the most significant comparison of transportation costs can be made by comparing the costs under the 1962 law to those under the 40/55/65/65-foot length limits (Step 3), which approach the limits indicated by changes in State laws since 1962. The changes are as follows for rigid pavement, all six highway systems, and 10 census divisions:

	Percentage change	
	Greatest decrease	Greatest increase (+) or least decrease (-)
a. Equivalent uniform annual highway cost	- 0.9	+ 1.3
b. Equivalent uniform annual motor vehicle operating cost	-30.1	- 2.1
c. Combined EUAHC and EUAMVOC	-25.3	- 1.4
d. Highway construction cost	- 0.9	+ 1.3
e. 1962 daily number of trucks	-39.2	- 6.8

On a straight dollar basis, the reductions from the 1962 base condition to Step 1 length limits in the National average (table 11-6) show a range of reduction of $95 (secondary rural) to $392 per mile (Interstate rural) in the equivalent annual uniform highway costs and a range of change in truck operating cost per mile of highway from an increase of $63 on the secondary rural system to a decrease of $33,249 per year per mile on the Interstate urban system.

Overall highway transportation economy would be increased materially by Nationwide use of the three-unit combination--tractor, semitrailer, and full trailer--with a maximum length of 65 feet. These increased length limits would result in a 14 to 27 percent reduction in the truck ADT from the 2D upward.

CHAPTER 12

ECONOMY OF SIMULTANEOUS INCREASES IN THE LIMITS OF AXLE WEIGHT AND OF VEHICLE LENGTH

The spread in the range of State maximum limits for both axle weight and vehicle length gives reason to consider the economy of simultaneous increases in axle-weight and length limits. Chapters 10 and 11 develop separately the transportation economy for axle weight and for vehicle length limits, respectively. It remains, then, to combine Methods 1-M (axle-weight economy) and 4 (vehicle length economy) into one analysis, identified as Method 6.

1. PLAN OF METHOD 6

The bases for comparison are the results of Method 1-M for axle-weight limits and a modification of Method 4, identified as Method 4-M, for the length limits prevailing in 1962. Thus, the economy of the combination of methods was tested for each of ten census divisions and six highway systems in a matrix of 25 cells--five axle-weight limits and five vehicle length limits, each including the 1962 legal status.

Method 4 was modified in one factor to become Method 4-M. Method 4 was based on the empty weights, horsepower, and tractor weights given in Chapter 14 and on the E 18-kip axle applications of Method 1 at the base condition. Method 4-M is Method 4 with the base E 18-kip axle applications adjusted upward to produce the minimum pavement depth used in Method 1-M. Therefore, Methods 1-M and 4-M are identical at Step 0 and the base (1962 law) axle-weight limit.

How Methods 1-M and 4-M were combined is explained in detail in the section on procedure for Method 6, which follows: The combination of methods, like the methods from which it is derived, includes the 29-percent increase in payload per vehicle from 1962 to 1990 and the transition period. The Method 6 analysis was made for rigid pavement only.

2. PROCEDURE USED IN METHOD 6

The plan followed for determining the transportation economy of simultaneous increases in axle-weight limits and vehicle length limits was a merging of the procedures for Methods 1-M and 4-M. The work involved in Method 6, therefore, was to compute the highway and vehicle costs for the interior cells of the matrix formed by four axle-weight levels above the minimum base of 18/32 kips and four length steps above the base of the 1962 legal limits.

In order to reduce the volume of detailed calculations and to hold assumptions to the minimum, a system of percentage relationships was developed, based upon Methods 1-M and 4-M, by which the ADT and the E 18-kip axle applications for each vehicle class could be extended to the right from the vertical and downward from the horizontal base cells to the interior cells. The matrix below indicates the cells where the cost data are supplied from Methods 1-M and 4-M and the blank cells to be filled in with costs developed by Method 6.

Method 4-M factor length limit—Step No.	Method 1-M factors				
	Single/tandem axle-weight limits, kips				
	18/32	20/35	22/38	24/41	26/44
0 (1962 law)	Method 1-M and Method 4-M	Method 1-M	Method 1-M	Method 1-M	Method 1-M
1	Method 4-M				
2	Method 4-M				
3	Method 4-M				
4	Method 4-M				

Note: The blank cells represent the combination of increases in axle weight and vehicle length for which highway and motor-vehicle cost data are to be supplied from Method 6.

3. RESULTS OF METHOD 6

To provide the basis for comparing the relative economy between any pair of the 25 cells, the base results for seven factors are summarized in table 12-1N for the six highway systems in the Nation as a whole.

Table 12-1N - Summary of highway and truck operating cost, truck ADT, and pavement depth under a range of axle-weight limits and of vehicle length limits; rigid pavement.

Note: Combination of Methods 1-M and 4 with transition period and with payload increase. Entries apply to one centerline-mile of new construction. Tons of payload varies, but is held constant for the axle weight limit level and vehicle length steps within a highway system and census division.

National summary -- System 1, Interstate rural

Cost item, number of trucks and pavement depth	Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44
Step 0 - 1962 legal weight and length limits					
Highway construction cost 1/	613,115	616,111	620,159	625,863	631,265
Equivalent uniform annual highway capital cost 2/	53,454	53,716	54,069	54,566	55,037
Equivalent uniform annual highway cost 3/	56,599	56,880	57,260	57,793	58,299
Equivalent uniform annual truck operating cost 2/	232,044	228,713	224,003	218,657	215,181
Total equivalent uniform annual transportation cost	288,643	285,593	281,263	276,450	273,480
Daily number of trucks - 1962/1990 4/	1035/2537	1005/2464	963/2342	912/2241	866/2132
Pavement depth (inches)	9.24	9.35	9.50	9.68	9.84
Step 1 - Maximum length of vehicle and combinations - feet 5/ 35/50/55/65					
Highway construction cost 1/	608,712	611,678	615,671	621,279	626,602
Equivalent uniform annual highway capital cost 2/	53,071	53,329	53,677	54,166	54,630
Equivalent uniform annual highway cost 3/	56,216	56,493	56,868	57,393	57,892
Equivalent uniform annual truck operating cost 2/	207,574	205,682	203,262	200,692	198,932
Total equivalent uniform annual transportation cost	263,790	262,175	260,130	258,085	256,824
Daily number of trucks - 1962/1990 4/	844/2125	818/2058	784/1973	744/1876	706/1785
Pavement depth (inches)	8.90	9.01	9.16	9.33	9.48
Step 2 - Maximum length of vehicle and combinations - feet 5/ 35/55/60/65					
Highway construction cost 1/	610,132	613,117	617,136	622,773	628,120
Equivalent uniform annual highway capital cost 2/	53,194	53,455	53,805	54,296	54,763
Equivalent uniform annual highway cost 3/	56,339	56,619	56,996	57,523	58,025
Equivalent uniform annual truck operating cost 2/	198,534	196,753	194,444	193,321	191,467
Total equivalent uniform annual transportation cost	254,873	253,372	251,440	250,844	249,492
Daily number of trucks - 1962/1990 4/	807/2024	782/1961	750/1880	711/1785	674/1697
Pavement depth (inches)	9.01	9.12	9.27	9.45	9.60
Step 3 - Maximum length of vehicle and combinations - feet 5/ 40/55/65/65					
Highway construction cost 1/	611,778	614,783	618,830	624,497	629,878
Equivalent uniform annual highway capital cost 2/	53,338	53,600	53,953	54,447	54,916
Equivalent uniform annual highway cost 3/	56,483	56,764	57,144	57,674	58,178
Equivalent uniform annual truck operating cost 2/	188,316	186,765	184,723	183,888	182,364
Total equivalent uniform annual transportation cost	244,799	243,529	241,867	241,562	240,542
Daily number of trucks - 1962/1990 4/	756/1905	733/1846	702/1871	666/1682	633/1601
Pavement depth (inches)	9.14	9.25	9.40	9.58	9.74
Step 4 - Maximum length of vehicle and combinations - feet 5/ 40/55/70/70					
Highway construction cost 1/	612,575	615,592	619,650	625,334	630,724
Equivalent uniform annual highway capital cost 2/	53,407	53,670	54,024	54,520	54,990
Equivalent uniform annual highway cost 3/	56,552	56,835	57,216	57,748	58,253
Equivalent uniform annual truck operating cost 2/	182,774	181,263	179,188	178,690	177,108
Total equivalent uniform annual transportation cost	239,326	238,098	236,404	236,438	235,361
Daily number of trucks - 1962/1990 4/	733/1844	711/1787	681/1713	646/1628	613/1548
Pavement depth (inches)	9.20	9.32	9.46	9.64	9.80

1/ Includes cost of pavement and shoulders, bridge structures, and earthwork and drainage.

2/ Calculated at 6 percent interest rate per annum and 20 years, 1965 through 1984.

3/ Includes annual cost of maintenance on surface and base, shoulders, and structures.

4/ Number includes only trucks from class 2D upward through two trailer combinations; step 0 through 2-trailer, 5 axle and other steps through 2-trailer, 9 axle.

5/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

Table 12-1N - Summary of highway and truck operating cost, truck ADT, and pavement depth under a range of axle-weight limits and of vehicle length limits; rigid pavement.

Note: Combination of Methods 1-M and 4 with transition period and with payload increase. Entries apply to one centerline-mile of new construction. Tons of payload varies, but is held constant for the axle weight limit level and vehicle length steps within a highway system and census division.

National summary -- System 2, Interstate urban

Cost item, number of trucks and pavement depth	Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44
Step 0 - 1962 legal weight and length limits					
Highway construction cost 1/	2,009,978	2,013,019	2,017,452	2,023,340	2,029,098
Equivalent uniform annual highway capital cost 2/	175,240	175,505	175,892	176,405	176,906
Equivalent uniform annual highway cost 3/	180,609	180,994	181,531	182,250	182,956
Equivalent uniform annual truck operating cost 2/	368,086	357,380	346,460	332,350	323,250
Total equivalent uniform annual transportation cost	548,695	538,374	527,991	514,600	506,206
Daily number of trucks - 1962/1990 4/	1466/4608	1410/4436	1341/4226	1248/3951	1169/3714
Pavement depth (inches)	9.31	9.39	9.50	9.64	9.78
Step 1 - Maximum length of vehicle and combinations - feet 5/ 35/50/55/65					
Highway construction cost 1/	2,008,385	2,011,423	2,015,841	2,021,704	2,027,428
Equivalent uniform annual highway capital cost 2/	175,101	175,366	175,751	176,262	176,761
Equivalent uniform annual highway cost 3/	180,470	180,855	181,390	182,107	182,811
Equivalent uniform annual truck operating cost 2/	333,403	325,503	316,357	303,800	296,513
Total equivalent uniform annual transportation cost	513,873	506,358	497,747	485,907	479,324
Daily number of trucks - 1962/1990 4/	1288/4085	1239/3926	1179/3733	1097/3472	1027/3260
Pavement depth (inches)	9.19	9.27	9.38	9.52	9.65
Step 2 - Maximum length of vehicle and combinations - feet 5/ 35/55/60/65					
Highway construction cost 1/	2,009,293	2,012,361	2,016,795	2,022,671	2,028,408
Equivalent uniform annual highway capital cost 2/	175,180	175,448	175,834	176,346	176,847
Equivalent uniform annual highway cost 3/	180,549	180,937	181,472	182,190	182,897
Equivalent uniform annual truck operating cost 2/	325,023	317,247	308,228	297,688	289,912
Total equivalent uniform annual transportation cost	505,572	498,184	489,700	479,878	472,809
Daily number of trucks - 1962/1990 4/	1261/3982	1213/3827	1153/3638	1072/3387	1003/3173
Pavement depth (inches)	9.26	9.35	9.46	9.60	9.73
Step 3 - Maximum length of vehicle and combinations - feet 5/ 40/55/65/65					
Highway construction cost 1/	2,011,144	2,014,209	2,018,668	2,024,570	2,030,333
Equivalent uniform annual highway capital cost 2/	175,342	175,609	175,998	176,512	177,015
Equivalent uniform annual highway cost 3/	180,711	181,098	181,636	182,357	183,066
Equivalent uniform annual truck operating cost 2/	296,294	289,464	281,547	272,637	265,747
Total equivalent uniform annual transportation cost	477,005	470,562	463,183	454,994	448,813
Daily number of trucks - 1962/1990 4/	1136/3606	1093/3465	1040/3296	968/3073	906/2879
Pavement depth (inches)	9.40	9.49	9.60	9.74	9.88
Step 4 - Maximum length of vehicle and combinations - feet 5/ 40/55/70/70					
Highway construction cost 1/	2,011,660	2,014,731	2,019,196	2,025,106	2,030,878
Equivalent uniform annual highway capital cost 2/	175,386	175,654	176,044	176,559	177,062
Equivalent uniform annual highway cost 3/	180,755	181,143	181,682	182,403	183,111
Equivalent uniform annual truck operating cost 2/	291,723	284,944	277,025	268,328	261,399
Total equivalent uniform annual transportation cost	472,478	466,087	458,707	450,731	444,510
Daily number of trucks - 1962/1990 4/	1121/3549	1078/3410	1025/3242	954/3022	892/2830
Pavement depth (inches)	9.44	9.53	9.64	9.79	9.92

1/ Includes cost of pavement and shoulders, bridge structures, and earthwork and drainage.

2/ Calculated at 6 percent interest rate per annum and 20 years, 1965 through 1984.

3/ Includes annual cost of maintenance on surface and base, shoulders, and structures.

4/ Number includes only trucks from class 2D upward through two trailer combinations; step 0 through 2-trailer, 5 axle and other steps through 2-trailer, 9 axle.

5/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

Table 12-1N- Summary of highway and truck operating cost, truck ADT, and pavement depth under a range of axle-weight limits and of vehicle length limits; rigid pavement.

Note: Combination of Methods 1-M and 4 with transition period and with payload increase. Entries apply to one centerline-mile of new construction. Tons of payload varies, but is held constant for the axle weight limit level and vehicle length steps within a highway system and census division.

National summary -- System 3, primary rural

Cost item, number of trucks and pavement depth	Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44
Step 0 - 1962 legal weight and length limits					
Highway construction cost 1/	298,472	298,964	299,758	300,834	301,871
Equivalent uniform annual highway capital cost 2/	26,022	26,065	26,134	26,228	26,319
Equivalent uniform annual highway cost 3/	28,002	28,048	28,121	28,221	28,318
Equivalent uniform annual truck operating cost 2/	56,018	54,860	53,425	51,892	50,992
Total equivalent uniform annual transportation cost	84,020	82,908	81,546	80,113	79,310
Daily number of trucks - 1962/1990 4/	364 / 460	353 / 446	338 / 426	319 / 403	302 / 382
Pavement depth (inches)	9.10	9.13	9.17	9.22	9.27
Step 1 - Maximum length of vehicle and combinations - feet 5/ 35/50/55/65					
Highway construction cost 1/	294,419	294,903	295,680	296,730	297,743
Equivalent uniform annual highway capital cost 2/	25,669	25,711	25,779	25,870	25,959
Equivalent uniform annual highway cost 3/	27,649	27,694	27,766	27,863	27,958
Equivalent uniform annual truck operating cost 2/	50,833	49,810	48,478	46,942	45,925
Total equivalent uniform annual transportation cost	78,482	77,504	76,244	74,805	73,883
Daily number of trucks - 1962/1990 4/	313 / 403	302 / 389	287 / 370	268 / 347	250 / 326
Pavement depth (inches)	8.73	8.76	8.79	8.84	8.89
Step 2 - Maximum length of vehicle and combinations - feet 5/ 35/55/60/65					
Highway construction cost 1/	295,888	296,376	297,160	298,220	299,241
Equivalent uniform annual highway capital cost 2/	25,797	25,840	25,908	26,000	26,089
Equivalent uniform annual highway cost 3/	27,777	27,823	27,895	27,994	28,089
Equivalent uniform annual truck operating cost 2/	48,816	47,847	46,567	45,306	44,314
Total equivalent uniform annual transportation cost	76,593	75,670	74,462	73,300	72,403
Daily number of trucks - 1962/1990 4/	301 / 386	291 / 373	276 / 354	258 / 332	241 / 311
Pavement depth (inches)	8.87	8.90	8.94	8.99	9.03
Step 3 - Maximum length of vehicle and combinations - feet 5/ 40/55/65/65					
Highway construction cost 1/	297,777	298,270	299,063	300,134	301,166
Equivalent uniform annual highway capital cost 2/	25,962	26,005	26,074	26,167	26,257
Equivalent uniform annual highway cost 3/	27,942	27,988	28,061	28,160	28,256
Equivalent uniform annual truck operating cost 2/	45,710	44,822	43,651	42,532	41,620
Total equivalent uniform annual transportation cost	73,652	72,810	71,712	70,692	69,876
Daily number of trucks - 1962/1990 4/	279 / 359	269 / 347	255 / 330	239 / 309	223 / 290
Pavement depth (inches)	9.05	9.08	9.12	9.17	9.22
Step 4 - Maximum length of vehicle and combinations - feet 5/ 40/55/70/70					
Highway construction cost 1/	298,729	299,224	300,023	301,098	302,136
Equivalent uniform annual highway capital cost 2/	26,045	26,088	26,158	26,251	26,342
Equivalent uniform annual highway cost 3/	28,025	28,071	28,145	28,244	28,341
Equivalent uniform annual truck operating cost 2/	44,797	43,921	42,755	41,677	40,780
Total equivalent uniform annual transportation cost	72,822	71,992	70,900	69,921	69,121
Daily number of trucks - 1962/1990 4/	273 / 352	264 / 340	250 / 323	234 / 303	219 / 284
Pavement depth (inches)	9.14	9.17	9.21	9.26	9.31

1/ Includes cost of pavement and shoulders, bridge structures, and earthwork and drainage.

2/ Calculated at 6 percent interest rate per annum and 20 years, 1965 through 1984.

3/ Includes annual cost of maintenance on surface and base, shoulders, and structures.

4/ Number includes only trucks from class 2D upward through two trailer combinations; step 0 through 2-trailer, 5 axle and other steps through 2-trailer, 9 axle.

5/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

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Table 12-1N- Summary of highway and truck operating cost, truck ADT, and pavement depth under a range of axle-weight limits and of vehicle length limits; rigid pavement.

Note: Combination of Methods 1-M and 4 with transition period and with payload increase. Entries apply to one centerline-mile of new construction. Tons of payload varies, but is held constant for the axle weight limit level and vehicle length steps within a highway system and census division.

National Summary -- System 4, primary urban

Cost item, number of trucks and pavement depth	Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44
Step 0 - 1962 legal weight and length limits					
Highway construction cost 1/	474,343	475,540	477,230	479,417	481,551
Equivalent uniform annual highway capital cost 2/	41,356	41,460	41,607	41,798	41,984
Equivalent uniform annual highway cost 3/	44,671	44,785	44,945	45,153	45,355
Equivalent uniform annual truck operating cost 2/	134,610	128,190	121,647	115,221	112,063
Total equivalent uniform annual transportation cost	179,281	172,975	166,592	160,374	157,418
Daily number of trucks - 1962/1990 4/	803/1292	758/1217	707/1133	650/1043	605/971
Pavement depth (inches)	9.10	9.15	9.22	9.30	9.37
Step 1 - Maximum length of vehicle and combinations - feet 5/ 35/50/55/65					
Highway construction cost 1/	472,488	473,679	475,361	477,532	479,650
Equivalent uniform annual highway capital cost 2/	41,194	41,298	41,444	41,634	41,818
Equivalent uniform annual highway cost 3/	44,509	44,623	44,782	44,989	45,189
Equivalent uniform annual truck operating cost 2/	118,152	114,052	109,873	105,297	102,828
Total equivalent uniform annual transportation cost	162,661	158,675	154,655	150,286	148,017
Daily number of trucks - 1962/1990 4/	688/1116	657/1061	621/1000	577/928	540/868
Pavement depth (inches)	8.94	9.00	9.06	9.14	9.21
Step 2 - Maximum length of vehicle and combinations - feet 5/ 35/55/60/65					
Highway construction cost 1/	473,440	474,636	476,325	478,505	480,633
Equivalent uniform annual highway capital cost 2/	41,277	41,381	41,528	41,718	41,904
Equivalent uniform annual highway cost 3/	44,692	44,706	44,866	45,073	45,276
Equivalent uniform annual truck operating cost 2/	115,425	111,437	107,360	103,187	100,732
Total equivalent uniform annual transportation cost	160,117	156,143	152,226	148,260	146,008
Daily number of trucks - 1962/1990 4/	675/1090	644/1036	609/977	565/906	529/847
Pavement depth (inches)	9.04	9.09	9.16	9.23	9.30
Step 3 - Maximum length of vehicle and combinations - feet 5/ 40/55/65/65					
Highway construction cost 1/	477,617	478,833	480,548	482,762	484,921
Equivalent uniform annual highway capital cost 2/	41,641	41,747	41,897	42,090	42,278
Equivalent uniform annual highway cost 3/	44,956	45,072	45,235	45,445	45,649
Equivalent uniform annual truck operating cost 2/	104,870	101,229	97,560	93,910	91,714
Total equivalent uniform annual transportation cost	149,826	146,301	142,795	139,355	137,363
Daily number of trucks - 1962/1990 4/	607/984	579/936	547/882	508/818	476/765
Pavement depth (inches)	9.43	9.48	9.55	9.63	9.70
Step 4 - Maximum length of vehicle and combinations - feet 5/ 40/55/70/70					
Highway construction cost 1/	478,116	479,335	481,055	483,273	485,436
Equivalent uniform annual highway capital cost 2/	41,684	41,791	41,941	42,134	42,323
Equivalent uniform annual highway cost 3/	44,999	45,116	45,279	45,489	45,694
Equivalent uniform annual truck operating cost 2/	103,440	99,827	96,167	92,569	90,374
Total equivalent uniform annual transportation cost	148,439	144,943	141,446	138,058	136,068
Daily number of trucks - 1962/1990 4/	600/971	572/922	540/869	502/806	469/753
Pavement depth (inches)	9.48	9.53	9.60	9.68	9.75

1/ Includes cost of pavement and shoulders, bridge structures, and earthwork and drainage.

2/ Calculated at 6 percent interest rate per annum and 20 years, 1965 through 1984.

3/ Includes annual cost of maintenance on surface and base, shoulders, and structures.

4/ Number includes only trucks from class 2D upward through two trailer combinations; step 0 through 2-trailer, 5 axle and other steps through 2-trailer, 9 axle.

5/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

Table 12-1N- Summary of highway and truck operating cost, truck ADT, and pavement depth under a range of axle-weight limits and of vehicle length limits; rigid pavement.

Note: Combination of Methods 1-M and 4 with transition period and with payload increase. Entries apply to one centerline-mile of new construction. Tons of payload varies, but is held constant for the axle weight limit level and vehicle length steps within a highway system and census division.

National summary -- System 5, secondary rural

Cost item, number of trucks and pavement depth	Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44
Step 0 - 1962 legal weight and length limits					
Highway construction cost 1/	147,537	147,675	147,849	148,064	148,280
Equivalent uniform annual highway capital cost 2/	12,863	12,875	12,890	12,909	12,928
Equivalent uniform annual highway cost 3/	13,387	13,400	13,416	13,436	13,456
Equivalent uniform annual truck operating cost 2/	10,068	9,777	9,451	9,048	8,816
Total equivalent uniform annual transportation cost	23,455	23,177	22,867	22,484	22,272
Daily number of trucks - 1962/1990 4/	64 / 92	61 / 89	59 / 84	55 / 79	51 / 74
Pavement depth (inches)	8.00	8.01	8.02	8.03	8.05
Step 1 - Maximum length of vehicle and combinations - feet 5/ 35/50/55/65					
Highway construction cost 1/	145,996	146,131	146,303	146,516	146,729
Equivalent uniform annual highway capital cost 2/	12,729	12,740	12,755	12,774	12,793
Equivalent uniform annual highway cost 3/	13,253	13,265	13,281	13,301	13,321
Equivalent uniform annual truck operating cost 2/	10,127	9,806	9,474	9,094	8,881
Total equivalent uniform annual transportation cost	23,380	23,071	22,755	22,395	22,202
Daily number of trucks - 1962/1990 4/	62 / 94	59 / 89	57 / 84	53 / 79	49 / 74
Pavement depth (inches)	7.77	7.78	7.79	7.80	7.81
Step 2 - Maximum length of vehicle and combinations - feet 5/ 35/55/60/65					
Highway construction cost 1/	146,456	146,593	146,767	146,979	147,193
Equivalent uniform annual highway capital cost 2/	12,769	12,781	12,796	12,814	12,833
Equivalent uniform annual highway cost 3/	13,293	13,306	13,322	13,341	13,361
Equivalent uniform annual truck operating cost 2/	9,877	9,570	9,236	8,887	8,683
Total equivalent uniform annual transportation cost	23,170	22,876	22,558	22,228	22,044
Daily number of trucks - 1962/1990 4/	61 / 91	58 / 87	55 / 82	51 / 77	48 / 72
Pavement depth (inches)	7.84	7.85	7.86	7.87	7.88
Step 3 - Maximum length of vehicle and combinations - feet 5/ 40/55/65/65					
Highway construction cost 1/	148,121	148,258	148,435	148,650	148,867
Equivalent uniform annual highway capital cost 2/	12,914	12,926	12,941	12,960	12,979
Equivalent uniform annual highway cost 3/	13,438	13,451	13,467	13,487	13,507
Equivalent uniform annual truck operating cost 2/	9,032	8,747	8,453	8,136	7,961
Total equivalent uniform annual transportation cost	22,470	22,198	21,920	21,623	21,468
Daily number of trucks - 1962/1990 4/	55 / 83	53 / 79	50 / 75	46 / 70	44 / 66
Pavement depth (inches)	8.09	8.10	8.11	8.12	8.14
Step 4 - Maximum length of vehicle and combinations - feet 5/ 40/55/70/70					
Highway construction cost 1/	148,270	148,407	148,583	148,799	149,016
Equivalent uniform annual highway capital cost 2/	12,927	12,939	12,954	12,973	12,992
Equivalent uniform annual highway cost 3/	13,451	13,464	13,480	13,500	13,520
Equivalent uniform annual truck operating cost 2/	8,942	8,658	8,371	8,051	7,870
Total equivalent uniform annual transportation cost	22,393	22,122	21,851	21,551	21,390
Daily number of trucks - 1962/1990 4/	55 / 82	52 / 78	50 / 74	46 / 69	43 / 65
Pavement depth (inches)	8.11	8.12	8.13	8.15	8.16

1/ Includes cost of pavement and shoulders, bridge structures, and earthwork and drainage.

2/ Calculated at 6 percent interest rate per annum and 20 years, 1965 through 1984.

3/ Includes annual cost of maintenance on surface and base, shoulders, and structures.

4/ Number includes only trucks from class 2D upward through two trailer combinations; step 0 through 2-trailer, 5 axle and other steps through 2-trailer, 9 axle.

5/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

Table 12-1N- Summary of highway and truck operating cost, truck ADT, and pavement depth under a range of axle-weight limits and of vehicle length limits; rigid pavement.

Note: Combination of Methods 1-M and 4 with transition period and with payload increase. Entries apply to one centerline-mile of new construction. Tons of payload varies, but is held constant for the axle weight limit level and vehicle length steps within a highway system and census division.

National Summary -- System 6, secondary urban

Cost item, number of trucks and pavement depth	Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44
Step 0 - 1962 legal weight and length limits					
Highway construction cost 1/	193,936	196,072	198,777	201,989	205,195
Equivalent uniform annual highway capital cost 2/	16,908	17,095	17,330	17,610	17,890
Equivalent uniform annual highway cost 3/	17,870	18,074	18,331	18,637	18,943
Equivalent uniform annual truck operating cost 2/	29,091	28,301	27,344	26,202	25,521
Total equivalent uniform annual transportation cost	46,961	46,375	45,675	44,839	44,464
Daily number of trucks - 1962/1990 4/	197/250	190/230	180/228	168/213	157/199
Pavement depth (inches)	8.00	8.02	8.05	8.08	8.12
Step 1 - Maximum length of vehicle and combinations - feet 5/ 35/50/55/65					
Highway construction cost 1/	192,377	194,510	197,210	200,415	203,616
Equivalent uniform annual highway capital cost 2/	16,772	16,958	17,194	17,473	17,752
Equivalent uniform annual highway cost 3/	17,734	17,937	18,195	18,500	18,805
Equivalent uniform annual truck operating cost 2/	26,952	26,312	25,548	24,629	24,098
Total equivalent uniform annual transportation cost	44,686	44,249	43,743	43,129	42,903
Daily number of trucks - 1962/1990 4/	178/229	171/221	163/210	152/196	143/184
Pavement depth (inches)	7.77	7.79	7.81	7.85	7.88
Step 2 - Maximum length of vehicle and combinations - feet 5/ 35/55/60/65					
Highway construction cost 1/	192,841	194,976	197,678	200,884	204,086
Equivalent uniform annual highway capital cost 2/	16,813	16,999	17,235	17,514	17,793
Equivalent uniform annual highway cost 3/	17,775	17,978	18,236	18,541	18,846
Equivalent uniform annual truck operating cost 2/	26,361	25,723	24,971	24,115	23,593
Total equivalent uniform annual transportation cost	44,136	43,701	43,207	42,656	42,439
Daily number of trucks - 1962/1990 4/	174/224	168/216	160/205	149/192	140/180
Pavement depth (inches)	7.84	7.86	7.89	7.92	7.95
Step 3 - Maximum length of vehicle and combinations - feet 5/ 40/55/65/65					
Highway construction cost 1/	193,992	196,129	198,835	202,047	205,252
Equivalent uniform annual highway capital cost 2/	16,913	17,100	17,335	17,615	17,895
Equivalent uniform annual highway cost 3/	17,875	18,079	18,336	18,642	18,948
Equivalent uniform annual truck operating cost 2/	23,902	23,336	22,671	21,930	21,470
Total equivalent uniform annual transportation cost	41,777	41,415	41,007	40,572	40,418
Daily number of trucks - 1962/1990 4/	167/202	151/195	144/185	134/173	126/162
Pavement depth (inches)	8.01	8.04	8.06	8.10	8.13
Step 4 - Maximum length of vehicle and combinations - feet 5/ 40/55/70/70					
Highway construction cost 1/	194,179	196,317	199,024	202,236	205,444
Equivalent uniform annual highway capital cost 2/	16,929	17,116	17,352	17,632	17,912
Equivalent uniform annual highway cost 3/	17,891	18,095	18,353	18,659	18,965
Equivalent uniform annual truck operating cost 2/	23,628	23,064	22,395	21,656	21,190
Total equivalent uniform annual transportation cost	41,519	41,159	40,748	40,315	40,155
Daily number of trucks - 1962/1990 4/	155/200	150/192	142/183	133/171	124/160
Pavement depth (inches)	8.04	8.06	8.09	8.12	8.16

1/ Includes cost of pavement and shoulders, bridge structures, and earthwork and drainage.

2/ Calculated at 6 percent interest rate per annum and 20 years, 1965 through 1984.

3/ Includes annual cost of maintenance on surface and base, shoulders, and structures.

4/ Number includes only trucks from class 2D upward through two trailer combinations; step 0 through 2-trailer, 5 axle and other steps through 2-trailer, 9 axle.

5/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

Actually, because table 12-1N gives the results of Methods 1-M, 4-M, and 6, it may be used in comparing the economy of increases in axle-weight limits, vehicle length, and of combined axle weight and length. The form of table 12-1N was chosen because (a) it adapts itself to presentation of the significant end products, (b) certain of the basic factors were previously presented in the results of Methods 1-M and 4-M, and (c) the decreasing highway costs from one length step to another prevent calculation of a benefit-cost ratio.

In table 12-2N, a summary and analysis of table 12-1N shows the ratio to the base values of the corresponding values at increased axle-weight limits and vehicle length limits. The values presented are (a) highway construction costs, (b) truck ADT, (c) equivalent uniform annual truck operating cost, and (d) equivalent uniform annual highway cost.

4. DISCUSSION OF THE RESULTS OF METHOD 6

The results of the analysis of economy of increases in axle-weight limit indicate high probable economy, as shown by the benefit-cost ratios in the lower right-hand corner of table 12-2N. The increases in vehicle lengths likewise result in pronounced truck operationg economy, as shown by the index ratios in the lower left-hand corner of table 12-2N. When the increase in axle-weight limits is accompanied by an increase in the vehicle length limits, the economy gained is still more striking.

Table 12-2A. Differences and ratios of highway cost, truck cost, and ADT, indicating the relative economy of increases in axle-weight limits and in vehicle length limits: rigid pavement.

Note: All costs are for one centerline-mile of highway. Construction cost includes cost of pavement and shoulders, bridge structures, and earthwork and drainage; maintenance cost includes annual cost on surface and base, shoulders and structures. Truck ADT in Step 0 includes trucks from class 2D upward through two-trailer 5 axle other steps through 2-trailer 9 axle.

Based on results from methods 1-M and 4 as given in table 12-1.
National summary -- System 1, Interstate rural

Step - Length	Single/tandem axle weight limits, kips: 18/32	20/35	22/38	24/41	26/44	Single/tandem axle weight limits, kips: 18/32	20/35	22/38	24/41	26/44
	Increase (+) or decrease (-) in construction cost from base					Increase (+) or decrease (-) in 1962 truck ADT from base				
0 (1962 law)	Base 613,115	+2,996	+7,044	+12,742	+18,150	Base 1,035	-30	-72	-123	-169
1 (35/50/55/65) 1/	-4,403	-1,437	+2,556	+8,164	+13,427	-191	-217	-251	-291	-329
2 (35/55/60/65) 1/	-2,983	+ 2	+4,021	+9,658	+15,005	-228	-253	-285	-324	-361
3 (40/55/65/65) 1/	-1,337	+1,668	+5,715	+11,382	+16,763	-279	-302	-333	-369	-402
4 (40/55/70/70) 1/	-540	+2,477	+6,535	+12,219	+17,609	-302	-324	-354	-389	-422
	Ratio of construction cost to base					Ratio of truck ADT to base				
0 (1962 law)	1.000	1.005	1.011	1.021	1.030	1.000	0.971	0.930	0.881	0.837
1 (35/50/55/65) 1/	0.993	0.998	1.004	1.013	1.022	0.815	0.790	0.757	0.719	0.682
2 (35/55/60/65) 1/	0.995	1.000	1.007	1.016	1.024	0.780	0.756	0.725	0.687	0.651
3 (40/55/65/65) 1/	0.998	1.003	1.009	1.019	1.027	0.730	0.708	0.678	0.643	0.612
4 (40/55/70/70) 1/	0.999	1.004	1.011	1.020	1.029	0.708	0.687	0.658	0.624	0.592
	Increase (+) or decrease (-) in equivalent uniform annual truck operating cost from base					Increase (+) or decrease (-) in equivalent uniform annual highway cost from base				
0 (1962 law)	Base 232,044	-3,331	-8,041	-13,387	-16,863	Base 56,597	+281	+661	+1,194	+1,700
1 (35/50/55/65) 1/	-24,470	-26,362	-28,782	-31,352	-33,112	-383	-106	+269	+794	+1,293
2 (35/55/60/65) 1/	-33,510	-35,291	-37,600	-38,723	-40,577	-260	+20	+397	+924	+1,426
3 (40/55/65/65) 1/	-43,728	-45,279	-47,521	-48,156	-49,680	-116	+165	+545	+1,075	+1,579
4 (40/55/70/70) 1/	-49,270	-50,781	-52,856	-53,354	-54,936	-47	+236	+617	+1,149	+1,654
	Ratio of equivalent uniform annual truck operating cost to base					Ratio of decrease in equivalent uniform annual truck operating cost to increase in equivalent uniform annual highway cost				
0 (1962 law)	1.000	0.986	0.965	0.942	0.927	—	11.9	12.2	11.2	9.9
1 (35/50/55/65) 1/	0.894	0.886	0.876	0.865	0.857	2/	2/	107.0	39.5	25.6
2 (35/55/60/65) 1/	0.855	0.848	0.838	0.833	0.825	2/	1764.6	94.7	41.9	28.5
3 (40/55/65/65) 1/	0.811	0.805	0.796	0.792	0.786	2/	274.4	86.8	44.8	31.5
4 (40/55/70/70) 1/	0.788	0.781	0.772	0.770	0.763	2/	215.2	85.7	46.4	33.2

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

2/ Highway construction cost decreases, therefore, the results are highly favorable.

Table 12-2N- Differences and ratios of highway cost, truck cost, and ADT, indicating the relative economy of increases in axle-weight limits and in vehicle length limits: rigid pavement.

Note: All costs are for one centerline-mile of highway. Construction cost includes cost of pavement and shoulders, bridge structures, and earthwork and drainage; maintenance cost includes annual cost on surface and base, shoulders and structures. Truck ADT in Step 0 includes trucks from class 2D upward through two-trailer 5 axle, other steps through 2-trailer 9 axle.

Based on results from methods 1-M and 4 as given in table 12-1. National summary -- System 2, Interstate urban

Step - Length	Single/tandem axle weight limits, kips					Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Increase (+) or decrease (-) in construction cost from base					Increase (+) or decrease (-) in 1962 truck ADT from base				
0 (1962 law)	Base 2,009,978	+3,041	+7,474	+13,362	+19,110	Base 1,466	-56	-125	-218	-297
1 (35/50/55/65) 1/	-1,593	+1,445	+5,866	+11,726	+17,450	-178	-227	-287	-369	-439
2 (35/55/60/65) 1/	-685	+2,383	+6,817	+12,693	+18,430	-205	-253	-313	-394	-463
3 (40/55/65/65) 1/	+1,166	+4,231	+8,690	+14,592	+20,355	-330	-373	-426	-498	-560
4 (40/55/70/70) 1/	+1,682	+4,753	+9,218	+15,128	+20,900	-345	-388	-441	-512	-574
	Ratio of construction cost to base					Ratio of truck ADT to base				
0 (1962 law)	1.000	1.001	1.004	1.007	1.009	1.000	0.962	0.915	0.851	0.797
1 (35/50/55/65) 1/	0.999	1.001	1.003	1.006	1.009	0.879	0.845	0.804	0.748	0.701
2 (35/55/60/65) 1/	1.000	1.001	1.003	1.006	1.009	0.860	0.827	0.786	0.731	0.684
3 (40/55/65/65) 1/	1.001	1.002	1.004	1.007	1.010	0.775	0.746	0.709	0.660	0.618
4 (40/55/70/70) 1/	1.001	1.002	1.005	1.008	1.010	0.765	0.735	0.699	0.651	0.608
	Increase (+) or decrease (-) in equivalent uniform annual truck operating cost from base					Increase (+) or decrease (-) in equivalent uniform annual highway cost from base				
0 (1962 law)	Base 318,086	-10,706	-21,626	-35,736	-44,836	Base 180,609	+385	+922	+1,641	+2,347
1 (35/50/55/65) 1/	-34,683	-42,583	-51,729	-64,286	-71,573	-139	+246	+781	+1,498	+2,202
2 (35/55/60/65) 1/	-43,063	-50,839	-59,858	-70,398	-78,174	-60	+328	+863	+1,581	+2,288
3 (40/55/65/65) 1/	-71,792	-78,622	-86,539	-95,449	-102,339	+102	+289	+1,027	+1,748	+2,457
4 (40/55/70/70) 1/	-76,363	-83,142	-91,061	-99,758	-106,687	+146	+534	+1073	+1,794	+2,502
	Ratio of equivalent uniform annual truck operating cost to base					Ratio of decrease in equivalent uniform annual truck operating cost to increase in equivalent uniform annual highway cost				
0 (1962 law)	1.000	0.971	0.941	0.903	0.878	—	27.8	23.5	21.8	19.1
1 (35/50/55/65) 1/	0.906	0.884	0.859	0.825	0.806	2/	173.1	66.2	42.9	32.5
2 (35/55/60/65) 1/	0.883	0.862	0.837	0.809	0.788	2/	155.0	69.4	44.5	34.2
3 (40/55/65/65) 1/	0.805	0.786	0.765	0.741	0.722	703.8	160.8	84.3	54.6	41.7
4 (40/55/70/70) 1/	0.793	0.774	0.753	0.729	0.710	523.0	155.7	84.9	55.6	42.6

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

2/ Highway construction cost decrease, therefore, the results are highly favorable.

Table 12-2N - Differences and ratios of highway cost, truck cost, and ADT, indicating the relative economy of increases in axle-weight limits and in vehicle length limits; rigid pavement.

Note: All costs are for one centerline-mile of highway. Construction cost includes cost of pavement and shoulders, bridge structures, and earthwork and drainage; maintenance cost includes annual cost on surface and base, shoulders and structures. Truck ADT in Step 0 includes trucks from class 2D upward through two-trailer 5 axle, other steps through 2-trailer 9 axle.

Based on results from methods 1-M and 4 as given in table 12-1. National summary -- System 3, primary rural

Step - Length	Single/tandem axle weight limits, kips					Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Increase (+) or decrease (-) in construction cost from base					Increase (+) or decrease (-) in 1962 truck ADT from base				
0 (1962 law)	Base 278,472	+492	+1,286	+2,262	+3,399	Base 364	-11	-26	-45	-62
1 (35/50/55/65) 1/	-4,053	-3,569	-2,792	-1,742	-729	-51	-62	-77	-96	-114
2 (35/55/60/65) 1/	-2,584	-2,096	-1,312	-252	+769	-63	-73	-88	-106	-123
3 (40/55/65/65) 1/	-695	-202	+591	+1,662	+2,694	-85	-95	-109	-125	-141
4 (40/55/70/70) 1/	-257	+752	+1,551	+2,626	+3,664	-91	-100	-114	-130	-145
	Ratio of construction cost to base					Ratio of truck ADT to base				
0 (1962 law)	1.000	1.002	1.004	1.008	1.011	1.000	0.970	0.929	0.876	0.830
1 (35/50/55/65) 1/	0.986	0.988	0.991	0.994	0.997	0.860	0.830	0.788	0.736	0.687
2 (35/55/60/65) 1/	0.991	0.993	0.995	0.999	1.002	0.827	0.799	0.758	0.709	0.662
3 (40/55/65/65) 1/	0.998	0.999	1.002	1.005	1.009	0.766	0.739	0.701	0.657	0.613
4 (40/55/70/70) 1/	1.001	1.002	1.005	1.009	1.012	0.750	0.725	0.687	0.643	0.602
	Increase (+) or decrease (-) in equivalent uniform annual truck operating cost from base					Increase (+) or decrease (-) in equivalent uniform annual highway cost from base				
0 (1962 law)	Base 56,018	-1,158	-2,593	-4,126	-5,026	Base 28,002	+46	+119	+219	+316
1 (35/50/55/65) 1/	-5,185	-6,208	-7,540	-9,076	-10,093	-353	-308	-236	-139	-44
2 (35/55/60/65) 1/	-7,202	-8,171	-9,451	-10,712	-11,704	-225	-179	-107	-8	+87
3 (40/55/65/65) 1/	-10,308	-11,196	-12,367	-13,486	-14,398	-60	-14	+59	+158	+254
4 (40/55/70/70) 1/	-11,221	-12,097	-13,263	-14,341	-15,238	+23	+69	+143	+242	+339
	Ratio of equivalent uniform annual truck operating cost to base					Ratio of decrease in equivalent uniform annual truck operating cost to increase in equivalent uniform annual highway cost				
0 (1962 law)	1.000	0.979	0.954	0.926	0.910	—	25.2	21.8	18.8	15.9
1 (35/50/55/65) 1/	0.907	0.889	0.865	0.838	0.820	2/	2/	2/	2/	2/
2 (35/55/60/65) 1/	0.871	0.854	0.831	0.809	0.791	2/	2/	2/	2/	134.5
3 (40/55/65/65) 1/	0.816	0.800	0.779	0.759	0.743	2/	2/	209.6	85.4	56.7
4 (40/55/70/70) 1/	0.800	0.784	0.763	0.744	0.728	487.9	175.3	92.7	59.3	44.9

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

2/ Highway construction cost decrease, therefore, the results are highly favorable.

Table 12-2N - Differences and ratios of highway cost, truck cost, and ADT, indicating the relative economy of increases in axle-weight limits and in vehicle length limits: rigid pavement.

Note: All costs are for one centerline-mile of highway. Construction cost includes cost of pavement and shoulders, bridge structures, and earthwork and drainage; maintenance cost includes annual cost on surface and base, shoulders and structures. Truck ADT is Step 0 includes trucks from class 2D upward through two-trailer 5 axle, other steps through 2-trailer 9 axle.

Based on results from methods 1-M and 4 as given in table 12-1.

National summary -- System 4, primary urban

Step - Length	Single/tandem axle weight limits, kips					Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Increase (+) or decrease (-) in construction cost from base					Increase (+) or decrease (-) in 1962 truck ADT from base				
0 (1962 law)	Base 474,343	+1,197	+2,887	+5,074	+7,208	Base 803	-45	-96	-153	-198
1 (35/50/55/65) 1/	-1,855	-664	+1,018	+3,189	+5,307	-115	-146	-182	-226	-263
2 (35/55/60/65) 1/	-903	+293	+1,982	+4,162	+6,290	-128	-159	-194	-238	-274
3 (40/55/65/65) 1/	+3,274	+4,490	+6,205	+8,419	+10,578	-196	-224	-256	-295	-327
4 (40/55/70/70) 1/	+3,773	+4,992	+6,712	+8,930	+11,093	-203	-231	-263	-301	-334
	Ratio of construction cost to base					Ratio of truck ADT to base				
0 (1962 law)	1.000	1.003	1.006	1.011	1.015	1.000	0.944	0.880	0.809	0.753
1 (35/50/55/65) 1/	0.996	0.999	1.002	1.007	1.011	0.857	0.818	0.773	0.719	0.672
2 (35/55/60/65) 1/	0.998	1.001	1.004	1.009	1.013	0.841	0.802	0.758	0.704	0.659
3 (40/55/65/65) 1/	1.007	1.009	1.013	1.018	1.022	0.756	0.721	0.681	0.633	0.593
4 (40/55/70/70) 1/	1.008	1.011	1.014	1019	1.023	0.747	0.712	0.672	0.625	0.584
	Increase (+) or decrease (-) in equivalent uniform annual truck operating cost from base					Increase (+) or decrease (-) in equivalent uniform annual highway cost from base				
0 (1962 law)	Base 134,610	-6,420	-12,963	-19,389	-22,547	Base 44,671	+114	+274	+482	+684
1 (35/50/55/65) 1/	-16,458	-20,558	-24,737	-29,313	-31,782	-162	-48	+111	+318	+518
2 (35/55/60/65) 1/	-19,185	-23,173	-27,250	-31,423	-33,878	+21	+35	+195	+402	+605
3 (40/55/65/65) 1/	-29,740	-33,381	-37,050	-40,700	-42,876	+285	+401	+564	+774	+978
4 (40/55/70/70) 1/	-31,170	-34,783	-38,443	-42,041	-44,236	+328	+445	+608	+818	+1,023
	Ratio of equivalent uniform annual truck operating cost to base					Ratio of decrease in equivalent uniform annual truck operating cost to increase in equivalent uniform annual highway cost				
0 (1962 law)	1.000	0.952	0.904	0.856	0.832	—	56.3	47.3	40.2	33.0
1 (35/50/55/65) 1/	0.878	0.847	0.816	0.782	0.764	2/	2/	222.9	92.2	61.4
2 (35/55/60/65) 1/	0.857	0.828	0.797	0.766	0.748	913.6	662.0	139.7	78.2	56.0
3 (40/55/65/65) 1/	0.779	0.752	0.725	0.698	0.681	104.4	83.2	65.7	52.6	43.9
4 (40/55/70/70) 1/	0.768	0.742	0.714	0.688	0.671	95.0	78.2	63.2	51.4	43.2

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

2/ Highway construction cost decreases, therefore, the results are highly favorable

Table 12-2N.- Differences and ratios of highway cost, truck cost, and ADT, indicating the relative economy of increases in axle-weight limits and in vehicle length limits: rigid pavement.

Note: All costs are for one centerline-mile of highway. Construction cost includes cost of pavement and shoulders, bridge structures, and earthwork and drainage; maintenance cost includes annual cost on surface and base, shoulders and structures. Truck ADT in Step 0 includes trucks from class 2D upward through two-trailer 5 axle, other steps through 2-trailer 9 axle.

Based on results from methods 1-M and 4 as given in table 12-1.

National summary -- System 5, secondary rural

Step - Length	Single/tandem axle weight limits, kips					Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Increase (+) or decrease (-) in construction cost from base					Increase (+) or decrease (-) in 1962 truck ADT from base				
0 (1962 law)	Base 147,537	+138	+312	+527	+743	Base 64	-3	-5	-9	-13
1 (35/50/55/65) 1/	-1,541	-1,406	-1,234	-1,021	-808	-2	-5	-7	-11	-15
2 (35/55/60/65) 1/	-1,081	-944	-770	-558	-344	-3	-6	-9	-13	-16
3 (40/55/65/65) 1/	+584	+721	+898	+1,113	+1,330	-9	-11	-14	-18	-20
4 (40/55/70/70) 1/	+733	+870	+1,046	+1,262	+1,479	-9	-12	-14	-18	-21
	Ratio of construction cost to base					Ratio of truck ADT to base				
0 (1962 law)	1.000	1.001	1.002	1.004	1.005	1.000	0.953	0.922	0.859	0.797
1 (35/50/55/65) 1/	0.989	0.990	0.992	0.993	0.995	0.969	0.922	0.891	0.828	0.766
2 (35/55/60/65) 1/	0.993	0.994	0.995	0.996	0.998	0.953	0.906	0.859	0.797	0.750
3 (40/55/65/65) 1/	1.004	1.005	1.006	1.008	1.009	0.859	0.828	0.781	0.719	0.688
4 (40/55/70/70) 1/	1.005	1.006	1.007	1.009	1.010	0.859	0.813	0.781	0.719	0.672
	Increase (+) or decrease (-) in equivalent uniform annual truck operating cost from base					Increase (+) or decrease (-) in equivalent uniform annual highway cost from base				
0 (1962 law)	Base 10,068	-291	-617	-1,020	-1,252	Base 13,387	+13	+29	+49	+69
1 (35/50/55/65) 1/	+59	-262	-594	-974	-1,187	-134	-122	-106	-86	-66
2 (35/55/60/65) 1/	-191	-498	-832	-1,181	-1,385	-94	-81	-65	-46	-26
3 (40/55/65/65) 1/	-1,036	-1,321	-1,615	-1,932	-2,107	+51	+64	+80	+100	+120
4 (40/55/70/70) 1/	-1,126	-1,410	-1,697	-2,017	-2,198	+64	+77	+93	+113	+133
	Ratio of equivalent uniform annual truck operating cost to base					Ratio of decrease in equivalent uniform annual truck operating cost to increase in equivalent uniform annual highway cost				
0 (1962 law)	1.000	0.971	0.939	0.899	0.876	—	22.4	21.3	20.8	18.1
1 (35/50/55/65) 1/	1.006	0.974	0.941	0.903	0.882	2/ 3/	3/	3/	3/	3/
2 (35/55/60/65) 1/	0.981	0.951	0.917	0.883	0.862	3/	3/	3/	3/	3/
3 (40/55/65/65) 1/	0.897	0.869	0.840	0.808	0.791	20.3	20.6	20.2	19.3	17.6
4 (40/55/70/70) 1/	0.888	0.860	0.831	0.800	0.782	17.6	18.3	18.2	17.8	16.5

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth, tractor, semitrailer and full trailer combination.

2/ Motor vehicle operating cost increase, therefore, benefits are negative.

3/ Highway construction cost decrease, therefore, the results are highly favorable.

Table 12-2N- Differences and ratios of highway cost, truck cost, and ADT, indicating the relative economy of increases in axle-weight limits and in vehicle length limits: rigid pavement.

Note: All costs are for one centerline-mile of highway. Construction cost includes cost of pavement and shoulders, bridge structures, and earthwork and drainage; maintenance cost includes annual cost on surface and base, shoulders and structures. Truck ADT is Step 0 includes trucks from class 2D upward through two-trailer 5 axle, other steps through 2-trailer 9 axle.

Based on results from methods 1-M and 4 as given in table 12-1.
National summary -- System 6, secondary urban

Step - Length	Single/tandem axle weight limits, kips					Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Increase (+) or decrease (-) in construction cost from base					Increase (+) or decrease (-) in 1962 truck ADT from base				
0 (1962 law)	Base 193,736	+2,136	+4,841	+8,053	+11,259	Base 197	-7	-17	-29	-40
1 (35/50/55/65) 1/	-1,559	+574	+3,274	+6,479	+9,680	-19	-26	-34	-45	-54
2 (35/55/60/65) 1/	-1,095	-1,040	+3,742	+6,948	+10,150	-23	-29	-37	-48	-57
3 (40/55/65/65) 1/	+56	+2193	+4,899	+8,111	+11,316	-40	-46	-53	-63	-71
4 (40/55/70/70) 1/	+243	+2,381	5,088	+8,300	+11,508	-42	-47	-55	-64	-73
	Ratio of construction cost to base					Ratio of truck ADT to base				
0 (1962 law)	1.000	1.011	1.025	1.042	1.058	1.000	0.964	0.914	0.853	0.797
1 (35/50/55/65) 1/	0.992	1.003	1.017	1.033	1.050	0.904	0.868	0.827	0.772	0.726
2 (35/55/60/65) 1/	0.994	1.005	1.019	1.036	1.052	0.883	0.853	0.812	0.756	0.711
3 (40/55/65/65) 1/	1.000	1.011	1.025	1.042	1.058	0.797	0.766	0.731	0.680	0.640
4 (40/55/70/70) 1/	1.001	1.012	1.026	1.043	1.059	0.787	0.761	0.721	0.675	0.629
	Increase (+) or decrease (-) in equivalent uniform annual truck operating cost from base					Increase (+) or decrease (-) in equivalent uniform annual highway cost from base				
0 (1962 law)	Base 29,091	-790	-1,747	-2,889	-3,570	Base 17,870	+204	+461	+767	+1,073
1 (35/50/55/65) 1/	-2,139	-2,779	-3,543	-4,462	-4,993	-136	+67	+325	+630	+935
2 (35/55/60/65) 1/	-2,730	-3,368	-4,120	-4,976	-5,498	-95	+108	+366	+671	+976
3 (40/55/65/65) 1/	-5,189	-5,755	-6,420	-7,161	-7,621	+5	+209	+466	+772	+1,078
4 (40/55/70/70) 1/	-5,463	-6,027	-6,696	-7,435	-7,901	+21	+225	+483	+789	+1,095
	Ratio of equivalent uniform annual truck operating cost to base					Ratio of decrease in equivalent uniform annual truck operating cost to increase in equivalent uniform annual highway cost				
0 (1962 law)	1.000	0.973	0.940	0.901	0.877	—	3.9	3.8	3.8	3.3
1 (35/50/55/65) 1/	0.926	0.904	0.878	0.847	0.828	2/	41.5	10.9	7.1	5.3
2 (35/55/60/65) 1/	0.906	0.884	0.858	0.829	0.811	2/	31.2	11.3	7.4	5.6
3 (40/55/65/65) 1/	0.822	0.802	0.779	0.754	0.738	1037.8	27.5	13.8	9.3	7.1
4 (40/55/70/70) 1/	0.812	0.793	0.770	0.744	0.728	260.1	26.8	13.9	9.4	7.2

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full combination/fourth tractor, semitrailer and full trailer combination.

2/ Highway construction cost decrease, therefore, the results are highly favorable.

But the economy of the combined increases in length and axle-weight limits is not the sum of the two individual economies, but usually less than the sum.

The extremely high benefit-cost ratios in the lower right-hand corner of table 12-2N are the result of just slight increases in the equivalent uniform annual highway costs. Any such slight increase in costs is somewhat lacking in precision, but when divided into the much larger sum of dollars of decrease in truck operating cost (benefit) produces a benefit-cost ratio too large to believe. Nevertheless, very high economy does exist, as indicated by footnote No. 2 on the table (table 12-2N) for those cells where the highway costs decrease with a combined increase in axle-weight limit and vehicle length limit.

The national figures (combined 10 census divisions) for each of the six highway systems offers a good picture of the overall consequences of combined increases in axle-weight limits and vehicle length limits. Table 12-4 is a national summary showing the results separately for each of the four length-limit steps. The benefit-cost ratios vary as follows:

System 1.	Interstate rural	0.9 to 7.3
System 2.	Interstate urban	9.7 to 24.9
System 3.	Primary rural	9.2 to 21.6
System 4.	Primary urban	10.7 to 37.3
System 5.	Secondary rural	8.8 to 33.9
System 6.	Secondary urban	1.5 to 4.7

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Table 12-4.- Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 1. Interstate rural — Method of Analysis 6 with transition — Census Division All

Cost item	STEP ONE (35/50/55/65) 1/ Rigid Pavement — Single/tandem axle weight maximum limits, kips					STEP TWO (35/55/60/65) 1/ Rigid Pavement — Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	215,847	218,387	220,765	222,996	224,953	217,249	219,821	222,229	224,488	226,469
b. Bridge structures	197,746	261,047	204,347	207,648	210,948	197,746	201,047	204,347	207,648	210,948
c. Earthwork and drainage	190,391	190,478	190,559	190,635	190,701	190,390	190,477	190,560	190,637	190,703
d. Total construction cost	603,984	609,912	615,671	621,279	626,602	605,385	611,345	617,136	622,773	628,120
2. Equivalent uniform annual capital cost *	52,658	53,175	53,677	54,166	54,630	52,780	53,300	53,805	54,296	54,763
3. Incremental annual cost										
a. Capital cost	–	517	502	489	464	–	520	505	491	467
b. Maintenance cost of pavement and shoulders	–	13	12	11	10	–	13	12	11	10
c. Maintenance cost of structures	–	25	25	25	25	–	25	25	25	25
d. Total equivalent uniform annual highway cost	–	555	539	525	499	–	558	542	527	502
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	210,599	206,567	203,262	200,692	198,932	201,476	197,614	194,444	193,321	191,467
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	4,032	3,305	2,570	1,760	–	3,862	3,170	1,123	1,854
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	7.3	6.1	4.9	3.5	–	6.9	5.8	2.1	3.7

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 1. Interstate rural   Method of Analysis 6 with transition   Census Division All

Cost item	STEP THREE (40/55/65/65) 1/ Rigid Pavement Single/tandem axle weight maximum limits, kips					STEP FOUR (40/55/70/70) 1/ Rigid Pavement Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/33	24/41	26/44	18/32	20/35	22/33	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	218,873	221,480	223,921	226,210	228,217	219,659	222,284	224,741	227,046	227,063
b. Bridge structures	197,746	201,047	204,347	207,648	210,948	197,746	201,047	204,347	207,648	210,948
c. Earthwork and drainage	190,389	190,477	190,562	190,639	190,713	190,389	190,479	190,562	190,640	190,708
d. Total construction cost	607,008	613,004	618,830	624,497	629,878	607,794	613,810	617,650	625,334	630,724
2. Equivalent uniform annual capital cost *	52,922	53,445	53,953	54,447	54,916	52,991	53,515	54,024	54,520	54,990
3. Incremental annual cost										
a. Capital cost	–	523	508	494	469	–	524	509	496	470
b. Maintenance cost of pavement and shoulders	–	13	12	11	10	–	13	12	11	10
c. Maintenance cost of structures	–	25	25	25	25	–	25	25	25	25
d. Total equivalent uniform annual highway cost	–	561	545	530	504	–	562	546	532	505
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	190,903	187,526	184,723	183,888	182,364	185,352	182,033	179,183	178,690	177,108
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	3,377	2,803	835	1,524	–	3,319	2,845	498	1,582
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	6.0	5.1	1.6	3.0	–	5.9	5.2	0.9	3.1

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 2. Interstate urban Method of Analysis 6 with transition Census Division All

Cost item	STEP ONE (35/50/55/65) 1/ Rigid Pavement Single/tandem axle weight maximum limits, kips					STEP TWO (35/55/60/65) 1/ Rigid Pavement Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	219,873	221,807	223,670	225,453	227,103	220,772	222,742	224,621	226,418	228,081
b. Bridge structures	1,291,193	1,295,211	1,299,229	1,303,246	1,307,264	1,291,193	1,295,211	1,299,229	1,303,246	1,307,264
c. Earthwork and drainage	492,815	492,882	492,945	493,005	493,061	492,815	492,882	492,945	493,007	493,063
d. Total construction cost	2,003,881	2,009,900	2,015,844	2,021,704	2,027,429	2,004,780	2,010,835	2,016,795	2,022,671	2,028,408
2. Equivalent uniform annual capital cost *	174,708	175,233	175,751	176,262	176,761	174,787	175,315	175,834	176,347	176,847
3. Incremental annual cost										
a. Capital cost	-	525	518	511	499	-	528	519	513	500
b. Maintenance cost of pavement and shoulders	-	15	14	13	12	-	15	14	13	13
c. Maintenance cost of structures	-	193	193	193	193	-	193	193	193	193
d. Total equivalent uniform annual highway cost	-	733	725	717	704	-	736	726	719	706
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	349,598	331,342	316,357	303,800	296,513	341,140	323,062	308,228	297,688	289,912
5. Incremental equivalent uniform decrements in annual vehicle operating cost	-	18,256	14,985	12,557	7,287	-	18,078	14,834	10,540	7,776
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	-	24.9	20.7	17.5	10.4	-	24.6	20.4	14.7	11.0

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 2. Interstate urban — Method of Analysis 6 with transition — Census Division All

Cost item	STEP THREE (40/55/65/65) 1/ Rigid Pavement — Single/tandem axle weight maximum limits, kips					STEP FOUR (40/55/70/70) 1/ Rigid Pavement — Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	222,605	224,584	226,492	228,316	230,004	223,117	225,105	227,020	228,852	230,548
b. Bridge structures	1,291,193	1,295,211	1,299,229	1,303,246	1,307,264	1,291,193	1,295,211	1,299,229	1,303,246	1,307,264
c. Earthwork and drainage	492,815	492,882	492,947	493,008	493,065	492,814	492,882	492,947	493,008	493,066
d. Total construction cost	2,006,613	2,012,677	2,018,668	2,024,570	2,030,333	2,007,124	2,013,198	2,019,196	2,025,106	2,030,878
2. Equivalent uniform annual capital cost *	174,947	175,475	175,998	176,512	177,015	174,991	175,521	176,044	176,559	177,062
3. Incremental annual cost										
a. Capital cost	–	528	523	514	503	–	530	523	515	503
b. Maintenance cost of pavement and shoulders	–	15	14	14	13	–	15	14	13	12
c. Maintenance cost of structures	–	193	193	193	193	–	193	193	193	193
d. Total equivalent uniform annual highway cost	–	736	730	721	709	–	738	730	721	708
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	310,391	294,549	281,547	272,637	265,747	305,812	290,035	277,025	268,328	261,399
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	15,842	13,002	8,910	6,890	–	15,777	13,010	8,697	6,929
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	21.5	17.8	12.4	9.7	–	21.4	17.8	12.1	9.8

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 3. Primary rural — Method of Analysis 6 with transition — Census Division All

Cost item	STEP ONE (35/50/55/65) 1/ Rigid Pavement. Single/tandem axle weight maximum limits, kips					STEP TWO (35/55/60/65) 1/ Rigid Pavement. Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	176,036	176,586	177,135	177,673	178,176	177,498	178,058	178,615	179,162	179,672
b. Bridge structures	30,831	31,324	31,816	32,308	32,801	30,831	31,324	31,816	32,308	32,801
c. Earthwork and drainage	86,690	86,710	86,729	86,749	86,766	86,690	86,710	86,729	86,750	86,768
d. Total construction cost	293,557	294,620	295,680	296,730	297,743	295,019	296,092	297,160	298,220	299,241
2. Equivalent uniform annual capital cost *	25,594	25,686	25,779	25,870	25,959	25,721	25,815	25,908	26,000	26,089
3. Incremental annual cost										
a. Capital cost	–	92	93	91	89	–	94	93	92	89
b. Maintenance cost of pavement and shoulders	–	2	2	2	2	–	2	2	3	2
c. Maintenance cost of structures	–	4	4	4	4	–	4	4	4	4
d. Total equivalent uniform annual highway cost	–	98	99	97	95	–	100	99	99	95
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	52,387	50,266	48,478	46,942	45,925	50,325	48,285	46,567	45,306	44,314
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	2,121	1,788	1,536	1,017	–	2,040	1,718	1,261	992
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	21.6	18.1	15.8	10.7	–	20.4	17.4	12.7	10.4

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 3. Primary rural — Method of Analysis 6 with transition — Census Division All

Cost item	STEP THREE (40/55/65/65) 1/ Rigid Pavement Single/tandem axle weight maximum limits, kips					STEP FOUR (40/55/70/70) 1/ Rigid Pavement Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	179,378	179,948	180,517	181,075	181,596	180,325	180,901	181,476	182,040	182,566
b. Bridge structures	30,831	31,324	31,816	32,308	32,801	30,831	31,324	31,816	32,308	32,801
c. Earthwork and drainage	86,689	86,710	86,730	86,751	86,769	86,691	86,710	86,731	86,750	86,769
d. Total construction cost	296,898	297,982	299,063	300,134	301,166	297,847	298,935	300,023	301,098	302,136
2. Equivalent uniform annual capital cost *	25,885	25,980	26,074	26,167	26,257	25,968	26,063	26,158	26,251	26,342
3. Incremental annual cost										
a. Capital cost	—	95	94	93	90	—	95	95	93	91
b. Maintenance cost of pavement and shoulders	—	2	2	2	2	—	2	2	2	2
c. Maintenance cost of structures	—	4	4	4	4	—	4	4	4	4
d. Total equivalent uniform annual highway cost	—	101	100	99	96	—	101	101	99	97
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	47,069	45,216	43,651	42,532	41,620	46,146	44,313	42,755	41,677	40,780
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	1,853	1,565	1,119	912	—	1,833	1,558	1,078	897
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	18.3	15.7	11.3	9.5	—	18.1	15.4	10.9	9.2

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 4. Primary urban — Method of Analysis 6 with transition — Census Division All

Cost item	STEP ONE (35/50/55/65) 1/ Rigid Pavement					STEP TWO (35/55/60/65) 1/ Rigid Pavement				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	178,183	178,978	179,765	180,535	181,254	179,131	179,934	180,729	181,508	182,235
b. Bridge structures	118,850	120,224	121,597	122,970	124,344	118,850	120,224	121,597	122,970	124,344
c. Earthwork and drainage	173,941	173,970	173,999	174,027	174,052	173,941	173,970	173,999	174,027	174,054
d. Total construction cost	470,974	473,172	475,361	477,532	479,650	471,922	474,128	476,325	478,505	480,633
2. Equivalent uniform annual capital cost *	41,062	41,254	41,444	41,634	41,818	41,145	41,337	41,528	41,718	41,904
3. Incremental annual cost										
a. Capital cost	–	192	190	190	184	–	192	191	190	186
b. Maintenance cost of pavement and shoulders	–	5	5	5	4	–	5	5	5	5
c. Maintenance cost of structures	–	12	12	12	12	–	12	12	12	12
d. Total equivalent uniform annual highway cost	–	209	207	207	200	–	209	208	207	203
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	123,777	115,987	109,873	105,297	102,828	121,011	113,365	107,360	103,187	100,732
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	7,790	6,114	4,576	2,469	–	7,646	6,005	4,173	2,455
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	37.3	29.5	22.1	12.3	–	36.6	28.9	20.2	12.1

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 4. Primary urban — Method of Analysis 6 with transition — Census Division All

Cost item	STEP THREE (40/55/65/65) 1/ Rigid Pavement Single/tandem axle weight maximum limits, kips					STEP FOUR (40/55/70/70) 1/ Rigid Pavement Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	183,283	184,122	184,951	185,763	186,521	183,780	184,623	185,457	186,273	187,035
b. Bridge structures	118,850	120,224	121,597	122,970	124,344	118,850	120,224	121,597	122,970	124,344
c. Earthwork and drainage	173,939	173,970	174,000	174,029	174,056	173,939	173,970	174,001	174,030	174,057
d. Total construction cost	476,072	478,316	480,548	482,762	484,921	476,569	478,817	481,055	483,273	485,436
2. Equivalent uniform annual capital cost *	41,506	41,702	41,897	42,090	42,278	41,550	41,746	41,941	42,134	42,323
3. Incremental annual cost										
a. Capital cost	–	196	195	193	188	–	196	195	193	189
b. Maintenance cost of pavement and shoulders	–	5	5	5	4	–	5	5	5	4
c. Maintenance cost of structures	–	12	12	12	12	–	12	12	12	12
d. Total equivalent uniform annual highway cost	–	213	212	210	204	–	213	212	210	205
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	109,791	102,923	97,560	93,910	91,714	108,348	101,519	96,167	92,569	90,374
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	6,868	5,363	3,650	2,196	–	6,829	5,352	3,598	2,195
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	32.2	25.3	17.4	10.8	–	32.1	25.2	17.1	10.7

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12.4 - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 5. Secondary rural — Method of Analysis 6 with transition — Census Division All

Cost item	STEP ONE (35/50/55/65) 1/ Rigid Pavement, Single/tandem axle weight maximum limits, kips					STEP TWO (35/55/60/65) 1/ Rigid Pavement, Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	102,465	102,536	102,612	102,693	102,774	102,925	102,988	103,075	103,156	103,238
b. Bridge structures	9,180	9,310	9,439	9,568	9,698	9,180	9,310	9,439	9,568	9,698
c. Earthwork and drainage	34,248	34,250	34,252	34,255	34,257	34,247	34,250	34,253	34,255	34,257
d. Total construction cost	145,893	146,096	146,303	146,516	146,729	146,352	146,558	146,767	146,979	147,193
2. Equivalent uniform annual capital cost *	12720	12,737	12,755	12,774	12,793	12,760	12,778	12,796	12,814	12,833
3. Incremental annual cost										
a. Capital cost	-	17	18	19	19	-	18	18	18	19
b. Maintenance cost of pavement and shoulders	-	0	0	0	0	-	0	0	0	0
c. Maintenance cost of structures	-	1	1	1	1	-	1	1	1	1
d. Total equivalent uniform annual highway cost	-	18	19	20	20	-	19	19	19	20
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	10,571	9,961	9,474	9,094	8,881	10,316	9,721	9,236	8,887	8,683
5. Incremental equivalent uniform decrements in annual vehicle operating cost	-	610	487	380	213	-	595	485	349	204
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	-	33.9	25.6	19.0	10.7	-	31.3	25.5	18.4	10.2

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 5. Secondary rural — Method of Analysis 6 with transition — Census Division All

Cost item	STEP THREE (40/55/65/65) 1/ Rigid Pavement Single/tandem axle weight maximum limits, kips					STEP FOUR (40/55/70/70) 1/ Rigid Pavement Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	104,589	104,663	104,743	104,827	104,911	104,737	104,811	104,891	104,975	105,060
b. Bridge structures	9,180	9,310	9,437	9,568	9,698	9,180	9,310	9,439	9,568	9,698
c. Earthwork and drainage	34,248	34,250	34,253	34,255	34,258	34,248	34,251	34,253	34,256	34,258
d. Total construction cost	148,017	148,223	148,435	148,650	148,867	148,165	148,372	148,583	148,799	149,016
2. Equivalent uniform annual capital cost *	12,905	12,923	12,941	12,960	12,979	12,918	12,936	12,954	12,973	12,992
3. Incremental annual cost										
a. Capital cost	–	18	18	19	19	–	18	18	19	19
b. Maintenance cost of pavement and shoulders	–	0	0	0	0	–	0	0	0	0
c. Maintenance cost of structures	–	1	1	1	1	–	1	1	1	1
d. Total equivalent uniform annual highway cost	–	19	19	20	20	–	19	19	20	20
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	9,415	8,881	8,453	8,136	7,961	9,325	8,791	8,371	8,051	7,870
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	534	428	317	175	–	534	420	320	181
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	28.1	22.5	15.9	8.8	–	28.1	22.1	16.0	9.1

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4.- Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984: National average

Highway System 6. Secondary urban — Method of Analysis 6 with transition — Census Division All

Cost item	STEP ONE (35/50/55/65) 1/ Rigid Pavement Single/tandem axle weight maximum limits, kips					STEP TWO (35/55/60/65) 1/ Rigid Pavement Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	102,381	102,572	102,771	102,975	103,174	102,844	103,037	103,239	103,444	103,644
b. Bridge structures	39,363	42,358	45,352	48,346	51,341	39,363	42,358	45,352	48,346	51,341
c. Earthwork and drainage	49,073	49,080	49,087	49,094	49,101	49,073	49,080	49,087	49,094	49,101
d. Total construction cost	190,817	194,010	197,210	200,415	203,616	191,280	174,475	197,678	200,884	204,086
2. Equivalent uniform annual capital cost *	16,636	16,915	17,194	17,473	17,752	16,677	16,955	17,235	17,514	17,793
3. Incremental annual cost										
a. Capital cost	–	279	279	279	279	–	278	280	279	279
b. Maintenance cost of pavement and shoulders	–	1	1	1	1	–	0	1	1	1
c. Maintenance cost of structures	–	25	25	25	25	–	25	25	25	25
d. Total equivalent uniform annual highway cost	–	305	305	305	305	–	303	306	305	305
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	28,167	26,728	25,548	24,629	24,098	27,575	26,139	24,971	24,115	23,593
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	1,439	1,180	919	531	–	1,436	1,168	856	522
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	4.7	3.9	3.0	1.7	–	4.7	3.8	2.8	1.7

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

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Table 12-4. - Comparison of highway cost and motor vehicle operating cost for five levels of axle weight maximum limits by each of four maximum length of vehicles, for the 20-year period 1965 through 1984 : National average

Highway System 6. Secondary urban — Method of Analysis 6 with transition — Census Division All

Cost item	STEP THREE (40/55/65/65) 1/ Rigid Pavement — Single/tandem axle weight maximum limits, kips					STEP FOUR (40/55/70/70) 1/ Rigid Pavement — Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	103,992	104,190	104,396	104,606	104,810	104,180	104,378	104,585	104,796	105,001
b. Bridge structures	39,363	42,358	45,352	48,346	51,341	39,363	42,358	45,352	48,346	51,341
c. Earthwork and drainage	49,073	49,080	49,087	49,095	49,101	49,073	49,080	49,087	49,094	49,102
d. Total construction cost	192,428	195,628	198,835	202,047	205,252	192,616	195,816	199,024	202,236	205,444
2. Equivalent uniform annual capital cost *	16,777	17,056	17,335	17,615	17,895	16,793	17,072	17,352	17,632	17,912
3. Incremental annual cost										
a. Capital cost	–	279	279	280	280	–	279	280	280	280
b. Maintenance cost of pavement and shoulders	–	1	1	1	1	–	1	1	1	1
c. Maintenance cost of structures	–	25	25	25	25	–	25	25	25	25
d. Total equivalent uniform annual highway cost	–	305	305	306	306	–	305	306	306	306
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	24,967	23,701	22,671	21,930	21,470	24,695	23,429	22,395	21,656	21,190
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	1,266	1,030	741	460	–	1,266	1,034	739	466
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	4.2	3.4	2.4	1.5	–	4.2	3.4	2.4	1.5

* Calculated at 6 percent interest rate per annum and 20 years.

1/ First figure is maximum length in feet of a single unit truck/second, tractor semitrailer combination/third, tractive truck and full trailer combination/fourth, tractor, semitrailer, and full trailer combination.

Just why the 0.9 ratio occurs on the Interstate rural system at the 24/41-kip limit was not investigated. Overall, however, the benefit-cost ratios are exceptionally high.

CHAPTER 13

SUMMARY AND ANALYSIS OF THE ECONOMY OF VEHICLE DIMENSIONS AND WEIGHTS BASED ON STUDIES MADE BY A. T. KEARNEY AND COMPANY UNDER RESEARCH CONTRACT

During 1964 and 1965, A. T. Kearney and Company, management consultants of Chicago, Illinois, under contract with the Bureau of Public Roads, made two studies to discover the advantages to be gained by liberalizing motor vehicle dimension and weight limits. This chapter outlines their approach, taken independently from those of the Bureau of Public Roads, and gives the main results of their studies.

The results of the consultant's studies were used by the Bureau of Public Roads to conduct an engineering economy analysis comparing the costs and related benefits of possible liberalizations of motor vehicle dimension and weight limits. Therefore, this chapter also presents a check on the economy of motor vehicle dimensions and weights developed in analysis Method 1 (Chapter 10).

1. PLAN OF STUDY

The 30 liberalized levels of dimensions and weights shown in table 13-1 were the basis of the consultant's studies. It was assumed that at each of these levels would be carried the line-haul cargo tonnage transported by highway vehicles in 1960, broken down by the commodity density ranges shown in table 13-2.

Table 13-1. -- Liberalized levels of vehicle dimension and axle weight limits studied by A. T. Kearney and Company

Liberalized level no.	Height, feet	Width, inches	Single/tandem axle limit, kips	Total length, feet	No. of cargo bodies	Cargo body length, feet	Vehicle classification included
1	13.5	96"	18/32	55	1	40	3-S2
2			22/38				3-S2
3			26/44				3-S2
4		102	18/32				3-S2
5			22/38				3-S2
6			26/44				3-S2
7		96	18/32	65	2	27	2-S2-3, 3-S2-4
8			22/38				2-S2-2, 3-S2-3, 3-S2-4
9			26/44				2-S1-2, 3-S2-2, 3-S2-4
10		102	18/32				2-S2-3, 3-S2-4
11			22/38				2-S2-2, 3-S2-4
12			26/44				2-S1-2, 3-S2-2, 3-S2-4
13		96	18/32	75		30	3-S2-3, 3-S2-4
14			22/38				2-S2-2, 3-S2-4
15			26/44				2-S1-2, 3-S2-3, 3-S2-4
16		102	18/32				3-S2-3, 3-S2-4
17			22/38				3-S2-2, 3-S2-4
18			26/44				2-S2-2, 3-S2-4
19		96	18/32	100		40	3-S2-4
20			22/38				3-S2-4
21			26/44				3-S2-3, 3-S2-4
22		102	18/32				3-S2-4
23			22/38				3-S2-4
24			26/44				3-S2-3, 3-S2-4
25		96	18/32		3	27	3-S2-3-3, 3-S2-4-4
26			22/38				3-S2-2-2, 3-S2-4-3, 3-S2-3-3, 3-S2-4-4
27			26/44				3-S1-2-2, 3-S2-3-2, 3-S2-4-4
28		102	18/32				3-S2-3-3, 3-S2-4-4
29			22/38				3-S2-3-3, 3-S2-4-4, 3-S2-4-3
30			26/44				3-S1-2-2, 3-S2-3-3, 3-S2-3-2, 3-S2-4-4

Table 13-2. --Commodity density levels 1/

Commodity density level	Density level, lb./cu.ft. Minimum	Maximum	Effective average	Commodities included 2/
A	---	---	6.0	Common carrier dispatch, miscellaneous
B	---	---	11.5	Common carrier dispatch, volume limit attained
C	---	---	23.5	Common carrier dispatch, weight limit attained
D	27.5	32.4	30.0	Lumber and dimension stock
E	32.5	37.4	35.0	Bag fertilizer and prepared feeds
F	42.5	47.4	45.0	Gasoline, primary forest products, dairy farm products, wheat, corn,
G	52.5	57.4	55.0	Kerosine, crude petroleum
H	57.5	57.5+	57.5+	Stone, gravel, sand, iron & steel scrap, phosphate rock, liquid fertilizer, cement slag, coal, 3/ and pulpwood logs 4/

1/ Taken from exhibit 2 of the Kearney report

2/ Includes Interstate Commerce Commission certified carriers of general freight (common carriers) and the 19 major commodities

3/ Coal is considered the "H" level although the density is 50 lb./cu.ft. because it is carried in an open top type cargo body for which the maximum density is 40.5 lb./cu.ft.

4/ Pulpwood logs are considered in the "H" level although the density is 45 lb./cu.ft. because they are carried in open top type cargo bodies for which the maximum critical density is 40.5 lb./cu.ft.

The average distance of haul and amount of load per trip were used to estimate the total vehicle miles for each commodity density level. The average load per trip varied according to the liberalized level of vehicle dimension and weight limits. The total vehicle miles for each liberalized level of dimension and weight is the sum of the vehicle miles of travel for all commodity density ranges.

The approach by means of liberalizing dimension and weight limits was based on the assumption that competitive factors would force the highway transportation industry to select a single type of trailer combination having the minimum number of axles necessary to carry the maximum permissible load. This assumption was the reason for the use of more than one class of vehicle within a liberalized level. It permitted use of the minimum number of axles for each commodity density range.

Of the total 1960 line-haul tonnage transported in highway vehicles, as shown in table 13-3, 67.37 percent was found to be accounted for by the 19 major commodities represented by commodity density levels designated D, E, F, G, and H in table 13-2. General freight, 7.26 percent of the total tonnage, is represented by commodity density levels A, B, and C. All other tonnage, which includes 40 additional miscellaneous commodities, amounted to 25.37 percent of the total. The "all-other-tonnage" group was analyzed using the portion that showed highway shipment characteristics similar to the average for the I.C. C. certified carriers of general freight.

Table 13-3. -- Line-haul tonnages transported in highway vehicles, by special classification, United States, 1960

As grouped and analyzed by A. T. Kearney and Company	Tons (add 000)	Percent of total
19 Major commodities	1,848,961	67.37%
ICC certified carriers of general freight*	199,228	7.26
All other tonnage	696,257	25.37
Total 1960 highway tonnage **	2,744,446	100.00%

Sources: * Class I and II data - Trinc's Blue Book of the Trucking Industry, 1961, Trinc Associates, Ltd., Washington, D.C. Class III data - Selected Statistics of Class III Motor Carriers of Property for the Year, 1960, Interstate Commerce Commission, Washington, D. C.

** Intercity Freight Haulage, by Commodity, Shipping Density and Type of Transport, 1960, M. F. Kent, Highway Research Board, 43rd Annual Meeting, Washington, D. C.

For both the 19 major commodities and the group comprising all other tonnage, the consultant reduced the total tons to be hauled by the tons moved on single-unit trucks carrying payload weight less than could be carried using the 1960 dimension and weight limits. Table 13-4 shows the resulting line-haul tons that would have been affected by liberalization of vehicle dimensions and weights and the respective vehicle-miles and ton-miles of travel. It should be noticed that there is an effective 40-percent reduction in the total tons hauled (2.74 to 1.64 billion tons).

As shown in table 13-4, although the 19 major commodities represent two-thirds of the total affected line-haul tonnage, they represent only one-third of the total vehicle-miles and ton-miles of travel. All other tonnage, accounting for 22 percent of the total affected line-haul tonnage, also represents roughly one-third of the total vehicle-miles and ton-miles of travel.

2. CORRELATION OF VEHICLE-MILE ESTIMATES

Based on the year 1960, the Kearney report estimated that 13.46 billion vehicle-miles of travel would have been affected by vehicle dimension and weight liberalization. The figure is based on reduction of the 1960 total line-haul tonnage by approximately 40 percent, representing the tonnage moved in single-unit vehicles at payloads less than those possible using the 1960 vehicle dimension and weight limits. It is also based on

Table 13-4. -- Estimated line-haul tonnage, miles of vehicle travel and ton-miles that would likely be affected by vehicle weight and size limit liberalization by special classification, 1960

As grouped and analyzed by A. T. Kearney and Company	Line-haul tons (add 000)	Miles of vehicle travel (add 000)	Ton-miles (add 000)
19 Major commodities	1,064,525	3,965,400	57,948,800
ICC certified carriers of general freight (1)	199,228	4,801,155	51,157,852
All other tonnage group	380,852	4,690,187	56,743,831
Total	1,644,605	13,456,742	165,850,483

(1) Includes ICC reported data for general freight commodity groups only. Other commodity groups transported by ICC certified carriers are included in the 19 major commodities and the all other tonnage data.

liberalized level no. 1 (3-S2, 55-foot overall length, 40-foot trailer, 96-inch width, 18/32-kip single/tandem axle weights) at maximum payload conditions.

For comparison, the publication HIGHWAY STATISTICS for 1960 reports 61.3 billion vehicle-miles of travel on main rural roads. The figure is based on all types of trucks and combinations, including single units. It also reflects all degrees of loading--empty, partially loaded, and fully loaded.

3. VEHICLE-MILE ESTIMATES

An illustration will convey a better understanding of the technique used to estimate line-haul vehicle mileage saved. If 450,000 pounds of freight were hauled 100 miles in 10 vehicles, each effectively limited by dimension and weight regulations to 45,000 pounds of payload (5-axle semitrailer combinations with gross vehicle weights of 73,000 pounds and empty weights of 28,000 pounds), the total line-haul mileage for these vehicles would be 1,000 miles. But if the vehicles were permitted to carry 50,000 pounds of payload each, it would take only 9 vehicles to carry the 450,000 pounds a distance of 100 miles. Nine vehicles times 100 miles results in 900 vehicle-miles which, when subtracted from 1,000 vehicle-miles, equals 100 vehicle-miles saved by the increase in payload carrying capacity from 45,000 to 50,000 pounds.

The miles of vehicle travel that could be and would likely be affected by liberalizing of vehicle dimension and weight limits were projected by the consultant to the year 1990, based on an average growth rate of 2.75 percent from 1960. These results are shown below in 5-year intervals:

Years	Miles of vehicle travel (1,000)
1965 to 1970	81,414,603
1970 to 1975	93,241,973
1975 to 1980	106,787,544
1980 to 1985	122,300,926
1985 to 1990	140,067,986
Total	543,813,032

Based on an assumed starting year of 1965 for authorizing increased vehicle dimension and weight limits--recognizing that conversion to increased limits would be authorized gradually by individual States--the consultant determined that a probable annual conversion rate of 10 percent, or a total of 10 years, would be required before all miles of vehicle travel were actually covered by increased vehicle limits. Therefore, the following adjustments were made in the projected miles of vehicle travel shown above, assuming that the 10-percent conversion rate, or a 10-year period starting with 1965 would be required before all States authorized the increased limits:

Years	Adjusted miles of vehicle travel (1,000)
1965 to 1970	24,865,975
1970 to 1975	75,099,323
1975 to 1980	106,787,544
1980 to 1985	122,300,926
1985 to 1990	140,067,986
Total	469,121,754

The effects of liberalizing motor vehicle dimension and weight limits to any of the 30 levels were determined for 1960 in terms of the miles saved as a percentage of the 13,456,742,000 vehicle-miles of travel that could have been affected in 1960. The resulting percentages are shown in table 13-5.

Based on the estimated rates of conversion by carriers to utilization of the 30 levels of vehicle dimensions and weights, the estimates in table 13-6 were made to show the potential accumulated decrease in miles of vehicle travel up to the year 1990 resulting from the line-haul transportation of freight in maximum payloads.

4. SECOND STUDY

A. T. Kearney and Company performed under a second contract for the express purpose of developing detail on trucking operations helpful in the design of pavements and calculations of operating costs for the line-haul trailer combination under increased dimensions and weights.

A. Developing Possible Liberalization-- Universal Application

To relate the 30 levels of dimension and weight limits to the degrees of pavement deterioration they cause, Kearney converted their effects to equivalent 18,000-pound axle applications (E 18 kips) for each census division. For instance, the Kearney report indicates that if highway freight in the New England census division were hauled in trailer combinations

Table 13-5. Estimated percent of miles of vehicle travel in line-haul transportation of freight that would not have been required in 1960 under 30 levels of increased vehicle dimension and weight limits1/

Liberal-ized dimen-sion and weight level no.	Cargo-body length, feet	Number of cargo bodies	Cargo-body width, inches	Single/tan-dem axle-weight limits, kips	Percentage of miles of vehicle travel
1	40	1	96	18/32	4.1
2				22/38	7.6
3				26/44	16.7
4			102	18/32	21.8
5				22/38	24.1
6				26/44	25.6
7	27	2	96	18/32	11.9
8				22/38	17.4
9				26/44	28.1
10			102	18/32	34.1
11				22/38	37.7
12				26/44	40.6
13	30		96	18/32	14.6
14				22/38	20.0
15				26/44	31.4
16			102	18/32	37.8
17				22/38	41.7
18				26/44	45.3
19	40		96	18/32	16.6
20				22/38	22.4
21				26/44	35.5
22			102	18/32	42.6
23				22/38	46.9
24				26/44	50.9
25	27	3	96	18/32	17.7
26				22/38	23.9
27				26/44	38.5
28			102	18/32	46.4
29				22/38	51.3
30				26/44	55.3

1/ Based on summary report of A. T. Kearney and Co.

Table 13-6. Projection from 1965 to 1990 of the potential decrease in accumulated vehicle-miles of travel resulting from line-haul transportation of freight in maximum payloads1/

Liberalized dimension and weight level no.	Cargo-body length, feet	Number of cargo bodies	Cargo-body width, inches	Single/tandem axle weight limits, kips	Potential decrease in billions of vehicle-miles of travel
1	40	1	96	18/32	Base
2				22/38	29.4 to 33.8
3				26/44	60.7 to 70.0
4			102	18/32	58.5 to 83.4
5				22/38	64.7 to 92.2
6				26/44	68.7 to 97.9
7	27	2	96	18/32	32.3 to 46.0
8				22/38	47.2 to 66.6
9				26/44	57.0 to 86.1
10			102	18/32	69.2 " 104.5
11				22/38	76.5 " 115.5
12				26/44	82.4 " 124.4
13	30		96	18/32	34.1 to 55.8
14				22/38	46.7 to 76.5
15				26/44	38.1 to 96.2
16			102	18/32	45.8 " 115.8
17				22/38	50.6 " 127.8
18				26/44	54.9 " 138.8
19	40		96	18/32	38.3 to 63.5
20				22/38	52.3 to 85.7
21				26/44	43.1 " 108.8
22			102	18/32	51.7 " 130.5
23				22/38	56.9 " 143.7
24				26/44	61.4 " 155.1
25	27	3	96	18/32	52.8 to 74.2
26				22/38	71.3 " 100.2
27				26/44	114.8 " 161.4
28			102	18/32	108.3 " 177.5
29				22/38	119.8 " 196.3
30				26/44	129.1 " 211.5

1/ Based on summary report of A. T. Kearney and Co.

of 55-foot overall length, with 40-foot semitrailers 96 inches wide, under 22,000-pound single- and 38,000-pound tandem-axle limitations, the total E 18-kip applications per mile of pavement would average 84,000 per year or 230 per day.

Table 13-7 indicates that universal use of the 27-foot doubles in combinations of 65-foot overall length and 102-inch width on all highway systems in the East North Central census division would produce 82 E 18-kip axle applications for every 100 E 18-kip axles it took in 1960 to haul the same amount of freight. The number of tons in each commodity density level, as a percentage of the total tons hauled, varies for the different census divisions. Therefore, the figures in table 13-7 are not necessarily representative of all census divisions.

B. Developing Possible Liberalization--
Separate Highway Systems

The phase of the second Kearney study related to separate highway systems was based on the reasoning that, for over-the-road operations, competitive factors would force the highway transportation industry to select two classes of trailer combinations, one of which would have the minimum number of axles necessary to carry the maximum permissible payload on the primary and secondary highway systems and the other class similarly selected for higher gross loads on the Interstate system.

Table 13-7. -- Liberalized levels of highway freight vehicles showing ratio of relocation in pavement damage as determined by A. T. Kearney and Company

Liberalized level no.*	Vehicle length, feet		Vehicle width, inches	Axle weight, kips		Ratio of anticipated to present E-18 effect, East North Central Census Division
	On secondary and primary systems	On Interstate systems		Single	Tandem	
0007	65 (27 doubles)	same	96	18	32	0.85
0010	65 (27 doubles)	same	102	18	32	0.82
0013	75 (30 doubles)	same	96	18	32	0.80
0016	75 (30 doubles)	same	102	18	32	0.85
0119	55 (40 single)	100 (40 double)	96	18	32	0.86
0422	55 (40 single)	100 (40 double)	102	18	32	0.99
0719	65 (27 double)	100 (40 double)	96	18	32	0.89
1022	65 (27 double)	100 (40 double)	102	18	32	0.95
1319	75 (30 double)	100 (40 double)	96	18	32	0.89
1622	75 (30 double)	100 (40 double)	102	18	32	0.93
0125	55 (40 single)	100 (27 triple)	96	18	32	0.78
0428	55 (40 single)	100 (27 triple)	102	18	32	0.85
0725	65 (27 double)	100 (27 triple)	96	18	32	0.73
1028	65 (27 double)	100 (27 triple)	102	18	32	0.81
1325	75 (30 double)	100 (27 triple)	96	18	32	0.73
1628	75 (30 double)	100 (27 triple)	102	18	32	0.80

* The first two digits represent the liberalized level permitted on secondary and primary highway systems. The third and forth digits represent the liberalized level permitted on the Interstate system.

Table 13-7 lists 12 of the 36 paired classes of trailer combinations that were studied by the consultant. In the right-hand column are the ratios of total anticipated E 18-kip axle applications of the paired classes to the total present E 18-kip effect of liberalized level number 1 of the 36 paired trailer-combinations classes studied by the consultant. The table lists those pairs having a ratio of anticipated to present E 18-kip effect of less than 1.00. The lowest or most favorable ratio shown is 0.73 for pairing of 27-foot double trailers (65-foot overall length) and 27-foot triple trailers (100-foot overall length), all of which are 96 inches wide.

5. APPLICATION OF THE KEARNEY FINDINGS

An important application of the results of the Kearney studies is to serve as an independent check of the in-house studies of the desirable dimensions and weights of motor vehicles reported upon here. But in order to compare the Kearney results with those obtained by the project staff, it is necessary to translate Kearney's E 18-kip applications based on maximum loading conditions to the E 18-kip axles developed in analysis Method 1 (Chapter 10) on the basis of 1962 loading practice. The following paragraphs outline the adjustments that were made in order to attain comparability in results.

The E 18-kip axles reported by Kearney were adjusted to account for traffic growth to 1965 from his base year 1960.

The average E 18-kip axles for the study period 1965 to 1984 were then determined using the electronic computer. The E 18-kip axles for passenger cars and single-unit trucks were also added to Kearney's total, because they are included in Method 1.

The base E 18-kip axles at the 18/32-kip single/tandem axle-weight level for the 40-foot semitrailer combination (liberalized level number 1) in each census division was adjusted to the E 18-kip values developed in Method 1 from the 1962 truck weight study at the 18/32-kip single/tandem axle-weight level. The E 18-kip axles for each of the remaining liberalized levels were adjusted by the percentage used for liberalized level number 1. The costs of highway construction for pavement shoulders, bridges, earthwork and drainage, and maintenance costs were calculated as described for Method 1 in Chapter 10.

Loaded and empty vehicle-miles of travel were reported by Kearney for each commodity density level. The motor vehicle operating costs used were those developed in Chapters 9 and 10. The total motor vehicle operating cost for each liberalized level of motor vehicle dimension and weight was obtained by adding together the operating costs of all the commodity levels.

Two adjustments were made in the total operating cost of each liberalized level of vehicle dimension and weight. To adjust to a level representative of the study period, the costs were multiplied by the ratio to the 1960 E 18's of the total average E 18-kip axles for the study period shown by the computer printout. Then, to adjust for correlation with Method 1, the factor used to adjust E 18's to Method 1 was also applied to motor vehicle operating costs. Benefit-cost ratios were then calculated using the procedure described for Method 1 in Chapter 10. The results are shown in table 13-9.

6. ECONOMY OF HIGHER AXLE-WEIGHT LEVELS

The range of benefit-cost ratios resulting from use of the Kearney data for 40-foot single-axle trailers confirms the range of benefit-cost ratios for increases in axle-weight limits shown by Method 1. The benefit-cost ratios based on Kearney data show economy in higher axle-weight limits for all vehicle classifications studied. Only the 40-foot, double-trailer combination indicated a low benefit-cost ratio. The reason for this exception can be traced to the fact that, for the 40-foot double trailers at the 18/32-kip single/tandem axle-weight level for vehicles 96 and 102 inches wide, two liberalized levels of vehicle dimension and weight represented limited conditions of payload weight for commodity density levels A, B, and C. For other liberalized levels of vehicle dimensions and number of trailers, at the above-stated conditions of vehicle axle weight and width, payloads were limited as to cube for commodity density levels A, B, and C, which range from 0 to 27.5 pounds per cubic foot.

Table 13-9. -- Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost between axle weight levels for primary rural systems

Census Division Region	Cargo body length (feet) and number of cargo body units	96 inch maximum vehicle width: Single/tandem axle weights in kips					102 inch maximum vehicle width: Single/tandem axle weights in kips				
		18/32	20/35	24/41	26/44	26/44	18/32	20/35	24/41	24/41	26/44
1. NE	40 ft. - single	-	5.0	5.4	5.6	5.7	-	4.7	4.9	5.3	5.7
	27 ft. - double	-	4.1	3.6	3.7	3.7	-	2.9	3.6	4.4	3.6
	30 ft. - double	-	3.6	3.7	4.1	3.8	-	3.3	3.2	3.7	3.7
	40 ft. - double	-	1.0	1.9	3.7	4.0	-	0.2	0.6	2.9	4.3
	27 ft. - triple	-	4.0	3.4	3.0	2.9	-	1.2	4.9	3.1	4.1
2. MA	40 ft. - single	-	6.1	6.5	7.4	7.9	-	5.2	5.9	6.9	8.1
	27 ft. - double	-	3.5	4.0	4.6	4.9	-	3.1	4.5	5.7	5.1
	30 ft. - double	-	7.8	6.6	5.4	3.4	-	3.9	5.1	5.5	5.2
	40 ft. - double	-	0.8	1.5	5.3	5.6	-	0.1	0.1	4.6	5.4
	27 ft. - triple	-	3.5	3.4	3.7	4.1	-	0.8	2.3	5.4	6.5
5. ENC	40 ft. - single	-	9.3	5.9	4.7	4.7	-	6.4	5.5	5.6	6.4
	27 ft. - double	-	4.9	4.5	4.4	4.3	-	4.7	5.0	4.8	3.6
	30 ft. - double	-	4.7	4.2	4.0	3.9	-	3.9	4.3	4.3	3.8
	40 ft. - double	-	0.3	1.1	4.1	3.9	-	0.0	0.1	4.0	3.5
	27 ft. - triple	-	4.6	4.1	3.5	3.5	-	4.3	5.1	5.0	3.9
6. WNC	40 ft. - single	-	8.3	5.9	4.6	3.6	-	8.2	5.5	4.3	3.4
	27 ft. - double	-	4.2	4.2	2.5	1.6	-	4.4	3.5	3.1	2.3
	30 ft. - double	-	5.2	3.7	2.8	1.7	-	4.8	3.7	2.6	1.8
	40 ft. - double	-	3.6	3.1	2.6	2.0	-	3.7	2.9	2.4	1.8
	27 ft. - triple	-	4.2	3.1	2.0	0.8	-	3.7	2.9	2.2	1.7
7. ESC	40 ft. - single	-	10.1	9.9	9.9	11.2	-	9.5	9.3	9.0	10.2
	27 ft. - double	-	7.5	7.1	6.6	7.4	-	6.1	6.9	6.7	6.4
	30 ft. - double	-	8.8	7.5	6.3	6.5	-	8.3	8.1	6.7	5.9
	40 ft. - double	-	3.0	5.0	6.7	6.6	-	2.4	4.5	6.1	6.4
	27 ft. - triple	-	7.8	7.3	6.3	6.1	-	2.6	5.4	7.5	7.2
8. WSC	40 ft. - single	-	24.3	18.8	14.9	13.0	-	17.6	14.5	13.8	14.2
	27 ft. - double	-	13.4	10.9	10.5	9.1	-	10.7	12.4	12.7	11.8
	30 ft. - double	-	14.3	11.2	9.1	8.7	-	12.0	11.1	10.8	8.4
	40 ft. - double	-	7.4	9.3	10.4	8.9	-	6.3	8.6	8.8	8.2
	27 ft. - triple	-	15.0	11.6	9.4	8.2	-	8.0	10.9	12.7	11.4
9. M	40 ft. - single	-	3.7	4.3	4.7	5.5	-	3.4	4.1	4.8	6.1
	27 ft. - double	-	3.6	3.3	3.0	2.9	-	3.9	3.4	2.9	2.1
	30 ft. - double	-	3.9	3.5	2.8	1.9	-	2.8	3.1	3.3	2.9
	40 ft. - double	-	2.1	2.6	3.1	2.7	-	4.6	3.4	2.5	1.7
	27 ft. - triple	-	7.7	5.0	3.1	1.8	-	6.8	4.8	3.3	2.1
10. P	40 ft. - single	-	2.4	3.8	4.9	6.9	-	2.6	3.7	5.0	7.6
	27 ft. - double	-	2.1	2.5	2.8	3.2	-	1.1	2.2	2.7	2.7
	30 ft. - double	-	1.7	2.7	3.0	2.9	-	2.0	2.8	2.9	2.4
	40 ft. - double	-	1.8	2.1	2.2	1.6	-	0.3	1.4	2.4	3.2
	27 ft. - triple	-	2.3	2.4	2.5	2.4	-	2.7	2.3	1.9	1.6

For commodity density levels A, B, and C, which together in this case account for some 75 percent of the total vehicle-miles of travel, an increase in axle-weight limits usually permitted the dropping of one axle, resulting in a lower gross vehicle weight and thus lower operating costs. But the condition of limited weight for the 18/32-kip single/tandem axle-weight level for the 40-foot double trailers did not permit the dropping of an axle when axle-weight limits were raised by Kearney to the 22/38-kip single/tandem level. Therefore, the net result of adding together the operating costs for all commodity levels was an operating-cost increase instead of a decrease.

7. INCREASED VEHICLE WIDTH

Increase in vehicle width from 96 inches to 102 inches results in increased payloads for commodities that fill cargo bodies as to cube: that is, when the vehicle is visibly fully loaded by volume. But the increase in width--and thus the increase in vehicle empty weight--decreases the allowable payload. The two conditions in which cube-full and weight-full trailers are increased in width are therefore economically counterbalancing.

Decisions as to the economy of increases in width for specific vehicle classifications must be based on the net result for all commodity density levels. In general, the benefit-cost ratios in table 13-10, based on the Kearney data, show that it would be economical to increase vehicle widths from 96 inches to 102 inches.

Table 13-10 Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost resulting from an increase in vehicle width from 96 inches to 102 inches on the Primary Rural Highway System

Census Division Region	Cargo body length (feet) and number of cargo body units	Single/tandem axle weights in kips				
		18/32	20/35	24/41	26/44	26/44
1. NE	40 ft. - single	44.1	28.6	21.9	20.1	19.3
	27 ft. - double	24.6	52.0	*	283.3	9.8
	30 ft. - double	21.0	*	*	*	*
	40 ft. - double	48.9	17.6	8.0	4.7	5.8
	27 ft. - triple	14.5	-	-	-	7.4
2. MA	40 ft. - single	40.3	27.3	22.9	20.5	23.1
	27 ft. - double	14.2	24.3	9.2	66.9	16.0
	30 ft. - double	9.4	-	-	-	-
	40 ft. - double	76.3	17.4	11.5	8.9	8.2
	27 ft. - triple	7.9	-	-	-	*
5. ENC	40 ft. - single	44.8	18.1	15.2	16.4	21.3
	27 ft. - double	13.7	29.8	110.3	65.7	10.8
	30 ft. - double	22.6	*	√	√	√
	40 ft. - double	32.6	14.2	8.4	78.7	6.9
	27 ft. - triple	5.5	-	-	√	10.6
6. WNC	40 ft. - single	21.1	19.0	14.9	12.0	14.7
	27 ft. - double	19.6	*	*	31.6	8.1
	30 ft. - double	24.6	*	√	-	-
	40 ft. - double	12.4	26.2	28.4	16.2	6.9
	27 ft. - triple	14.0	*	-	*	4.5
7. ESC	40 ft. - single	69.9	38.8	30.3	25.4	22.8
	27 ft. - double	28.5	*	*	*	12.0
	30 ft. - double	26.7	*	√	-	√
	40 ft. - double	34.0	14.5	11.5	9.5	9.1
	27 ft. - triple	21.6	-	-	*	10.9
8. WSC	40 ft. - single	89.7	34.7	22.1	20.5	28.3
	27 ft. - double	12.1	-7.3	-0.3	16.8	19.6
	30 ft. - double	57.4	-	-	-	-
	40 ft. - double	41.3	22.9	18.6	14.5	13.3
	27 ft. - triple	20.3	-	-	-	15.4
9. M	40 ft. - single	0.9	0.0	0.4	0.0	0.2
	27 ft. - double	10.8	*	*	*	4.9
	30 ft. - double	10.5	4.6	3.7	7.2	*
	40 ft. - double	7.6	25.8	52.6	30.3	11.1
	27 ft. - triple	29.6	-	-	-	1.4
10. P	40 ft. - single	-1.5	2.5	2.3	2.7	3.1
	27 ft. - double	20.8	41.7	13.3	89.2	*
	30 ft. - double	15.0	*	*	*	*
	40 ft. - double	14.4	0.6	0.5	0.4	4.7
	27 ft. - triple	*	*	*	*	13.1

* Annual highway costs decreased and annual motor vehicle operating costs decreased.

\- Annual highway costs decreased and annual motor vehicle operating costs increased by an equal or greater amount.

√ Annual highway costs decreased and annual vehicle operating costs increased by a lesser amount.

The only vehicle classifications for which increased width is indicated to be questionable economy are the 27-foot double and triple trailers and the 30-foot double trailer. Reasons can be given for these conditions. For commodities resulting in loads with limited cubes, there is a limit of increased vehicle width and thus of payload and gross vehicle weight where additional axles are needed in order to prevent axle-weight overload. Additional axles mean lower E 18-kip axle applications and highway costs but also higher practical maximum gross vehicle weights and vehicle operating costs. Therefore, for those commodity density levels where an increase in width was accompanied by the need for an additional axle, there are no benefits or decreases in motor vehicle operating costs. The liberalized levels of motor vehicle dimension and weight that contained one or more commodity density levels requiring additional axles for an increase in vehicle width from 96 inches to 102 inches are shown below:

Commodity density level 1/	Liberalized level number		Vehicle classification
	96-inch vehicle width	102-inch vehicle width	
D, E	8	11	27-foot doubles
A,B,C.	15	18	27-foot doubles
A,B,C,D,E	26	29	27-foot triples
E	27	30	27-foot triples

1. See table 13-2 for types of commodities.

The need for additional axles is the significant factor in determining the economy of increasing width from 96 inches to 102 inches for the 27-foot trailers. For the 30-foot double trailer combination, it was found that a correction of the Kearney vehicle empty weight to show orderly increases in empty weight with increases in width would cause the 30-foot double-trailer combination to show economy for increases of width from 96 inches to 102 inches.

8. SUMMARY

The engineering economy analyses based on the studies of A. T. Kearney and Company indicate that economy is to be gained from the use of higher axle-weight limits than those now existing. The analyses, therefore, verify the findings of Method 1.

The analyses also indicate that general overall economy can be gained by increasin vehicle width from 96 inches to 102 inches.

The A. T. Kearney and Company studies indicate that there would be economic and service advantages for the trucking industry in the use of trailers with double-cargo as compared with single-cargo bodies. State legal overall length limits of 65 feet would be necessary before adequate double-trailer combinations could be operated.

CHAPTER 14

TRANSPORTATION FACTORS IN HAULING 2,000 TONS OF PAYLOAD ONE MILE AND THE MARGINAL LIMITS OF VEHICLE WEIGHTS

Understanding of the significance of the results in chapters 10, 11, and 12 on the economy of axle weight and vehicle length may be enhanced by a study of the equivalent 18-kip axle applications and motor vehicle operating cost which result from hauling 2,000 tons of payload one mile by each individual class of vehicle and by hypothetical fleets. A logical extension of both the analysis of the economy of axle weight and vehicle length and of the 2,000 ton study is to determine the ultimate limits of axle weight and gross vehicle weight beyond which there would be no further economy of transportation.

1. EMPTY WEIGHT OF VEHICLES RELATED TO AXLE-WEIGHT AND GROSS WEIGHT LIMITS

The trucking industry is desirous of keeping the empty, or tare, weight of vehicle as low as is sound, consistent with safety, dependability, reasonable operating cost, and suitability to the cargo carried. As axle weight increases, the vehicle empty weight must also increase to provide the desirable structural strength and braking ability. As the gross vehicle weight increases, the weight of the power vehicle must also increase to provide for the desired speed and acceleration.

A. Tare Weight of Tractors

Table 14-1 gives the tare weight of 2-axle and 3-axle tractors for a range of practical maximum gross combination weights from 25,000 to 280,000 pounds. This table was developed by reference to manufacturers' catalogs and truck weight data, and extended by judgment.

B. Weights of Empty Trailers

By reference to manufacturers' catalogs and other sources of information, table 14-2 was prepared to show the average weight of empty trailers by length and number of axles. In general, these weights correspond closely to the weight of the closed-van trailer and to axle-weight limits of 18/32 kips. From tables 14-1 and 14-2 it is possible to develop the empty weight of any tractor-trailer combination according to trailer length and axle arrangement.

C. Empty Weights of Various Vehicle Classes
at a Range of Axle-Weight Limits

The tare (empty) weights in tables 14-1 and 14-2 plus other information were used as the basis for obtaining the weights for specific classes of vehicles at specific lengths as given in table 14-3 for the 18/32 kip axle-weight limit.

Table 14-1. -- Net horsepower and tare weight of tractor related to practical maximum gross vehicle combination weight based upon truck weight studies, manufacturers' data, and judgment.

Practical maximum gross combination weight to be pulled, 1,000 pounds	Net available horsepower	Tare weight of tractor, pounds [1]	
		2-axle	3-axle
25	128	6,220	
30	138	6,800	10,300
40	158	7,960	11,250
50	178	9,120	12,200
60	198	10,280	13,150
70	218	11,440	14,100
80	238	12,600	15,050
90	258	13,760	16,000
100	278	14,920	16,950
120	318	17,240	18,850
140	358	19,560	20,750
160	398	21,880	22,650
180	338		24,550
200	378		26,450
220	418		28,350
240	458		30,250
260	498		32,150
280	638		34,050

[1] The tare weight reflects any added weight necessary for increased axle-weight limits because of the resulting increase in practical maximum gross vehicle weight.

Table 14-2. -- Weight in pounds of empty trailers for use in combinations of vehicles at the 18/32 single/tandem axle-weight limits

Trailer width of 96 inches.

Weight of dollies: single-axle, 2,600 pounds; two-axle, 5,000 pounds.

Trailer length, feet	Semitrailer		Full trailer		
	1 axle	2 axles	2 axles	3 axles	4 axles
20	6,300		8,900		
22	6,570		9,170		
24	6,840		9,440		
25	6,975	9,120	9,575	11,720	14,120
26	7,110	9,310	9,710	11,910	14,310
27	7,245	9,500	9,845	12,100	14,500
28	7,380	9,690	9,980	12,290	14,690
30	7,650	10,070	10,250	12,670	15,070
32	7,920	10,450	10,520	13,050	15,450
35	8,325	11,020	10,925	13,620	16,020
40	9,000	11,970	11,600	14,570	16,970
42	9,270	12,350	11,870	14,950	17,350
45	9,675	12,920	12,275	15,520	17,920

Table 14-3.-- Empty weights of different classes of vehicles and combinations for different length limits and combinations of vehicles

Class of vehicle		Single-unit truck		Tractor-semitrailer		Tractor-semitrailer & full trailer		30-foot tractive truck & full trailer			
	Total length limit, feet	35	40	50	55	65	70	55	60	65	70
	Trailer length, feet	-	-	40	45	27	29.5	22	27	32	37
2-D		10,100	10,775								
3-A		13,800	14,750								
2-S1				17,400	18,075						
2-S2				22,070	23,020						
3-S2				26,370	27,320						
2-S1-2						29,790	30,330				
2-S2-3						37,600	38,360				
3-S2-4						44,500	45,260				
2-2								22,325	23,000	23,675	24,350
3-2								25,325	26,000	26,675	27,350
3-3								28,125	28,800	29,475	30,150

Table 14-4 gives the empty weights of the single-unit trucks 2D and 3A and of the tractor-semitrailer series for the range of axle-weight limits from 18/32 to 60/95 kips.

The increase in tare weight with increased axle-weight limits was extended from the 18/32 limits by the use of the 1963 truck weight data. A plot was made of truck empty weights versus practical maximum gross vehicle weights. The practical maximum gross vehicle weight that would exist at each axle-weight level was obtained by first determining from the graph the increment of tare weight for each increment of practical maximum gross vehicle weight based on the next higher axle-weight limit.

D. Practical Maximum Gross Vehicle Weights

To calculate the number of vehicles required to haul 2,000 tons of payload and the operating cost of these vehicles, it is necessary to determine the practical maximum gross weights. For this computation, the practical maximum gross vehicle weight is defined as the sum of the maximum legal weights of the load-carrying axles plus the weight on the front, or steering axle. Table 14-5 gives the practical maximum gross vehicle weights for the same series of classes of vehicles and axle-weight limits as were used in table 14-4.

Table 14-4.-- Empty weights of various vehicle classifications for axle-weight limits up to 60/95 kips

Vehicle Class	Item	Single/tandem axle-weight limits - kips												
		18/32	20/35	22/38	24/41	26/44	28/47	32/53	36/59	40/65	44/71	48/77	52/83	60/95
2D	Incremental empty weight	-	2,200	1,800	1,600	1,500	1,400	2,220	1,900	1,700	1,600	1,500	1,475	2,725
	Total empty weight	9,220	11,420	13,220	14,820	16,320	17,720	19,920	21,820	23,520	25,120	26,620	28,095	30,820
3A	Incremental empty weight	-	1,430	1,290	1,200	1,150	1,050	2,000	1,900	1,800	1,700	1,500	1,400	2,800
	Total empty weight	15,640	17,070	18,360	19,560	20,710	21,760	23,760	25,560	27,360	29,060	30,560	31,960	34,760
2-S1	Incremental tractor weight	-	500	500	500	500	500	1,000	1,000	1,000	1,000	1,000	1,000	2,000
	Incremental trailer weight	-	1,150	950	800	700	600	1,100	1,000	900	800	700	600	1,050
	Total empty weight	17,400	19,050	20,500	21,800	23,000	24,100	26,200	28,200	30,100	31,900	33,600	35,200	38,250
2-S2	Incremental tractor weight	-	625	625	625	625	625	1,250	1,250	1,250	1,250	1,250	1,250	2,500
	Incremental trailer weight	-	875	775	675	625	565	1,020	910	810	710	610	510	800
	Total empty weight	22,070	23,570	24,970	26,270	27,520	28,710	30,980	33,140	35,200	37,160	39,020	40,780	44,080
3-S2	Incremental tractor weight	-	650	650	650	650	650	1,300	1,300	1,300	1,300	1,300	1,300	2,600
	Incremental trailer weight	-	875	775	700	650	600	1,100	1,000	900	800	700	600	1,050
	Total empty weight	26,370	27,895	29,320	30,670	31,970	33,220	35,620	37,920	40,120	42,220	44,220	46,120	49,770
2-S1-2	Incremental tractor weight	-	975	975	975	975	975	1,950	1,950	1,950	1,950	1,950	1,950	3,900
	Incremental trailer weight	-	2,300	1,900	1,600	1,400	1,200	2,200	2,000	1,800	1,600	1,400	1,200	2,100
	Total empty weight:													
	Using 27' trailers	29,790	33,065	35,940	38,515	40,890	43,065	47,215	51,165	54,915	58,465	61,815	64,965	70,965
	Using 40' trailers	33,300	36,575	39,450	42,025	44,400	46,575	50,725	54,675	58,425	61,975	65,325	68,475	74,475
2-S2-3	Incremental tractor weight	-	975	975	975	975	975	1,950	1,950	1,950	1,950	1,950	1,950	3,900
	Incremental trailer weight	-	1,750	1,550	1,400	1,300	1,200	2,200	2,000	1,800	1,600	1,400	1,200	2,100
	Total empty weight:													
	Using 27' trailers	37,600	40,325	42,850	45,225	47,500	49,675	53,825	57,775	61,525	65,075	68,425	71,575	77,575
	Using 40' trailers	42,540	45,265	47,790	50,165	52,440	54,615	58,765	62,715	66,465	70,015	73,365	76,515	82,515
3-S2-4	Incremental tractor weight	-	1,175	1,175	1,175	1,175	1,175	2,350	2,350	2,350	2,350	2,350	2,350	4,700
	Incremental trailer weight	-	1,750	1,550	1,400	1,300	1,200	2,200	2,000	1,800	1,600	1,400	1,200	2,100
	Total empty weight:													
	Using 27' trailers	44,500	47,425	50,150	52,725	55,200	57,575	62,125	66,475	70,625	74,575	78,325	81,875	88,675
	Using 40' trailers	49,440	52,365	55,090	57,665	60,140	62,515	67,065	71,415	75,565	79,515	83,265	86,815	93,615

Table 14-5 -- Practical maximum gross weights of several classes of vehicles for axle-weight limits up to 60/95 kips

Vehicle class	Axle type	Single/tandem axle-weight limits - kips												
		18/32	20/35	22/38	24/41	26/44	28/47	32/53	36/59	40/65	44/71	48/77	52/83	60/95
2D	Steering	7.4	8.2	9.0	9.8	10.6	11.4	13.0	14.6	16.2	17.8	19.4	21.0	24.2
	Drive single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Total	25.4	28.2	31.0	33.8	36.6	39.4	45.0	50.6	56.2	61.8	67.4	73.0	84.2
3A	Steering	9.6	10.2	10.8	11.4	12.0	12.6	13.8	15.0	16.2	17.4	18.8	19.8	22.2
	Drive tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Total	41.6	45.2	48.8	52.4	56.0	59.6	66.8	74.0	81.2	88.4	95.6	102.8	117.2
2-S1	Steering	7.6	8.0	8.3	8.5	8.6	8.7	8.9	9.1	9.3	9.5	9.7	9.9	10.3
	Drive single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Semi-single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Total	43.6	48.0	52.3	56.5	60.6	64.7	72.9	81.1	89.3	97.5	105.7	113.9	130.3
2-S2	Steering	8.4	8.7	9.0	9.3	9.6	9.9	10.5	11.1	11.7	12.3	12.9	13.5	14.7
	Drive single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Semi-tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Total	58.4	63.7	69.0	74.3	79.6	84.9	95.5	106.1	116.7	127.3	137.9	148.5	169.7
3-S2	Steering	9.7	10.0	10.3	10.6	10.9	11.2	11.8	12.4	13.0	13.6	14.2	14.8	16.0
	Drive tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Semi-tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Total	73.7	80.0	86.3	92.6	98.9	105.2	117.8	130.4	143.0	155.6	168.2	180.8	206.0
2-S1-2	Steering	8.7	8.9	9.1	9.3	9.5	9.7	10.1	10.5	10.9	11.3	11.7	12.1	12.9
	Drive single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Semi-single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Trailer single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Trailer single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Total	80.7	88.9	97.1	105.3	113.5	121.7	138.1	154.5	170.9	187.3	203.7	220.1	252.9
2-S2-3	Steering	9.3	9.7	10.1	10.5	10.9	11.3	12.1	12.9	13.7	14.5	15.3	16.1	17.7
	Drive single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Semi-tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Trailer single	18.0	20.0	22.0	24.0	26.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	60.0
	Trailer tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Total	109.3	119.7	130.1	140.5	150.9	161.3	182.1	202.9	223.7	244.5	265.3	286.1	317.7
3-S2-4	Steering	10.0	10.3	10.6	10.9	11.2	11.5	12.1	12.7	13.3	13.9	14.5	15.1	16.3
	Drive tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Semi-tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Trailer tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Trailer tandem	32.0	35.0	38.0	41.0	44.0	47.0	53.0	59.0	65.0	71.0	77.0	83.0	95.0
	Total	138.0	150.3	162.6	174.9	187.2	199.5	224.1	248.7	273.3	297.9	322.5	347.1	396.3

2. EQUIVALENT 18-KIP AXLE APPLICATIONS AND VEHICLE OPERATING COSTS RESULTING FROM HAULING 2,000 TONS OF PAYLOAD IN DIFFERENT CLASSES OF VEHICLES AND FLEETS

Added understanding of the interrelationships of axle-weight limits, E 18-kip axle applications, and cost of motor vehicle operation can be gained by studying each class of vehicle and vehicle fleet under hypothetical conditions. In the following analyses, the role of each class of vehicle in hauling 2,000 tons of payload freight is observed first in single vehicle classes, then in three fleets composed of different classes of vehicles.

A. Concept and Basic Provisions

A general conception of the relationship of the factors of (1) legal axle-weight limits, (2) E 18-kip axle-weight applications (applications of equivalent 18,000-pound single axles), (3) number of trucks eliminated under higher axle-weight and gross vehicle-weight limits, and (4) motor vehicle operating costs can be gained by considering these four factors in relation to haulage of a specific number of tons of payload, such as 2,000 tons (4,000,000 pounds) by the following classes and combinations of vehicles: (1) each of eight different classes of vehicles (scheme 1); (2) single-unit trucks, 40-foot semi-trailers (scheme 2); (3) single-unit trucks, 40-foot semi-trailers, and double 27-foot trailers with an overall vehicle combination length limit of 65 feet (scheme 3); and (4) single-unit trucks, 40-foot semitrailers, and double 40-foot trailers with an overall combination length limit of 100 feet (scheme 4).

The eight vehicle classes that were analyzed either separately or in combination are listed below:

1. 2-axle, 6-tire single-unit truck (2D)
2. 3-axle, single-unit truck (3A)
3. 3-axle tractor-semitrailer combination (2-S1)
4. 4-axle tractor-semitrailer combination (2-S2)
5. 5-axle tractor-semitrailer combination (3-S2)
6. 5-axle tractor-semitrailer-full-trailer combination (2-S1-2)
7. 7-axle tractor-semitrailer-full-trailer combination (2-S2-3)
8. 9-axle tractor-semitrailer-full-trailer combination (3-S2-4)

This analysis assumes that the 2,000 tons of payload are moved one highway mile with the appropriate number of empty trips and trips with full and less than full payloads. For purposes of further approach to reality, it may be assumed that these 2,000 tons of freight are hauled in one day. This tonnage approximates that which is now hauled daily over many routes on the rural primary systems.

It was assumed that, for the transportation of the 2,000 tons of highway freight in each part of the study, each vehicle class is loaded identically in relation to payload capacity. The loading distribution used, from the standpoint of weights, was as follows:

1. 33% of the vehicles move empty,
2. 17% of the vehicles move one-fourth loaded,

3. 30% of the vehicles move three-fourths loaded, and
4. 20% of the vehicles move fully loaded.

Varying empty weights (see table 14-6) -- depending upon the scheme of hauling the freight being considered -- were subtracted from the practical maximum gross weight (table 14-5) to get the maximum payload weight capacity for each vehicle class at each of the five axle-weight levels.

Using these maximum payload weights per vehicle, the pounds of payload at empty weight, one-fourth loaded, three-fourths loaded, and fully loaded were determined. These payloads at various degrees of loading were used for two purposes: (1) to calculate an average payload for each class of vehicle at each axle-weight limit and (2) by adding them back to the empty weights, to get the gross weights at the four levels of loading at increased axle-weight limits.

By dividing the number of tons that a particular class of vehicle is to haul by the average payload for that vehicle in table 14-7, the number of vehicles in each class required to transport the 2,000 tons of highway freight was determined. These numbers of vehicles then were distributed according to the assumed degree of loading in order to calculate the total number of E 18-kip axles by vehicle class.

Table 14-6.-- Empty weights of each of eight classes of vehicles and combinations hauling 2,000 tons of freight at various axle-weight limits

Axle weight limits, kips	2D	3A	2-S1	2-S2	3-S2	2-S1-2	2-S2-3	3-S2-4
SCHEME 1 - Using each of eight different vehicle classes at 65 feet maximum length								
18/32	10,100	13,800	16,000	22,070	26,370	29,790	37,600	44,500
20/35	12,300	15,230	17,650	23,570	27,895	33,065	40,325	47,425
22/38	14,100	16,520	19,100	24,970	29,320	35,940	42,850	50,150
24/41	15,700	17,720	20,400	26,270	30,670	38,515	45,225	52,725
26/44	17,200	18,870	21,600	27,520	31,970	40,890	47,500	55,200
SCHEME 2 - Using single-unit trucks and 40-foot semitrailers at 55 feet maximum length								
18/32	9,220	15,640	17,400	22,070	26,370			
20/35	11,420	17,070	19,050	23,570	27,895			
22/38	13,220	18,360	20,500	24,970	29,320			
24/41	14,820	19,560	21,800	26,270	30,670			
26/44	16,320	20,710	23,000	27,520	31,970			
SCHEME 3 - Using single-unit trucks, 40-foot semitrailers, and double 27-foot trailers at 65 feet maximum length								
18/32	9,220	15,640	17,400	22,070	26,370	29,790	37,600	44,500
20/35	11,420	17,070	19,050	23,570	27,895	33,065	40,325	47,425
22/38	13,220	18,360	20,500	24,970	29,320	35,940	42,850	50,150
24/41	14,820	19,560	21,800	26,270	30,670	38,515	45,225	52,725
26/44	16,320	20,710	23,000	27,520	31,970	40,890	47,500	55,200
SCHEME 4 - Using single-unit trucks, 40-foot semitrailers, and double 40-foot trailers at 100 feet maximum length								
18/32	9,220	15,640	17,400	22,070	26,370	33,300	42,540	49,440
20/35	11,420	17,070	19,050	23,570	27,895	36,575	45,265	52,365
22/38	13,220	18,360	20,500	24,970	29,320	39,450	47,790	55,090
24/41	14,820	19,560	21,800	26,270	30,670	42,025	50,165	57,665
26/44	16,320	20,710	23,000	27,520	31,970	44,400	52,440	60,140

Table 14-7. -- Average payloads in pounds carried in eight classes of vehicles for four different schemes of hauling 2,000 tons of freight at various axle-weight limits

Axle weight limits	2D	3A	2-S1	2-S2	3-S2	2-S1-2	2-S2-3	3-S2-4
SCHEME 1 - Using each of eight different vehicle classes at 65 feet maximum length*								
18/32	7,152	12,997	12,903	16,984	22,126	23,801	33,519	43,712
20/35	7,434	14,011	14,189	18,760	24,359	26,103	37,107	48,094
22/38	7,900	15,091	15,521	20,584	26,638	28,592	40,789	52,570
24/41	8,461	16,213	16,876	22,454	28,952	31,222	44,541	57,116
26/44	9,069	17,358	18,233	24,347	31,289	33,945	48,339	61,710
SCHEME 2 - Using single-unit trucks and 40-foot semitrailers at 55 feet maximum length								
18/32	7,565	12,136	12,249	See Scheme 1	See Scheme 1			
20/35	7,845	13,151	13,534					
22/38	8,313	14,231	14,867					
24/41	8,874	15,353	16,223					
26/44	10,481	16,498	17,578					
SCHEME 3 - Using single-unit trucks, 40-foot semitrailers, and double 27-foot trailers at 65 feet maximum length								
18/32	See Scheme 2	See Scheme 2	See Scheme 2	See Scheme 1	See Scheme 1	23,801	33,520	43,712
20/35						26,103	37,107	48,094
22/38						28,592	40,789	52,570
24/41						31,222	44,541	57,116
26/44						33,945	48,339	61,710
SCHEME 4 - Using single-unit trucks, 40-foot semitrailers, and double 40-foot trailers at 100 feet maximum length								
18/32	See Scheme 2	See Scheme 2	See Scheme 2	See Scheme 1	See Scheme 1	22,159	31,210	41,402
20/35						24,462	34,799	45,784
22/38						26,951	38,480	50,261
24/41						29,581	42,231	54,808
26/44						32,305	46,030	59,400

* With scheme 1 each of the eight different classes of vehicle in turn is assumed to carry the full 2,000 tons of payload.

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B. Scheme 1: Hauling 2,000 Tons of Freight by one Vehicle Class

One way to study the desirable dimensions and weights of motor vehicles is to assume that the 2,000 tons of highway freight move between points A and B in each of eight classes of highway freight vehicles and at five different axle-weight limits. Instead of moving the freight in a fleet of mixed classes of vehicles, the freight movement in one class of vehicle is assumed, to provide a comparison of the relative efficiencies of each of the eight vehicle classes.

It will be noted in table 14-8 that, under 18/32-kip axle-weight limitations (18,000 pounds for single and 32,000 pounds for tandem axles), the fewest vehicles (91.51) required to haul 2,000 tons of highway freight would result from using the 3-S2-4 vehicle. In addition, it should also be noted that, of the six trailer combinations, the 3-S2-4 vehicle would transmit to the pavement the fewest E 18-kip axles (189.67) in carrying 2,000 tons of payload.

It will be noted further that the 3-S2 vehicle, with two tandem axles and a steering axle, has 189.42 E 18-kip axles at 18/32-kip limitations, which increases to 482.10 at 26/44-kip limitations, an increase of 154 percent. The 2-S1-2 vehicle, with four single axles in addition to the steering axle, has 232.42 E 18-kip axles at the 18/32-kip limitations, increasing to 758.93 at the 26/44-kip limitations, an increase of

Table 14-8. -- Scheme 1: Average payloads, number of vehicles, number of E 18-kip axles, and dollars of transport cost necessary to move 2,000 tons of freight in each of eight classes of vehicles and at various axle-weight limits

Axle weight limit	Item	2D	3A	2-S1	2-S2	3-S2	2-S1-2	2-S2-3	3-S2-4
18/32	Average payload, lb.	7,152	12,997	12,903	16,984	22,126	23,801	33,519	43,712
	Number of vehicles required	559.28	307.76	310.01	235.52	180.78	168.06	119.34	91.51
	Number of E 18-kip axles	193.41	159.35	210.10	208.15	189.42	232.42	208.93	189.67
	Dollars of transport cost	$191.44	111.81	113.51	91.66	75.28	72.28	58.87	52.07
20/35	Average payload, lb.	7,434	14,011	14,189	18,760	24,359	26,103	37,107	48,094
	Number of vehicles required	538.07	285.49	281.91	213.22	164.21	153.24	107.80	83.17
	Number of E 18-kip axles	285.22	213.80	294.81	279.11	247.88	330.33	280.00	249.06
	Dollars of transport cost	185.98	105.20	105.06	84.91	70.39	68.49	55.99	50.34
22/38	Average payload, lb.	7,900	15,091	15,521	20,584	26,638	28,592	40,789	52,570
	Number of vehicles required	506.33	265.06	257.72	194.33	150.16	139.90	98.07	76.09
	Number of E 18-kip axles	406.95	280.76	410.81	362.08	311.53	449.29	363.77	319.55
	Dollars of transport cost	176.76	99.10	97.75	79.23	66.29	65.03	53.64	48.98
24/41	Average payload, lb.	8,461	16,213	16,876	22,454	28,952	31,222	44,541	57,116
	Number of vehicles required	472.76	246.72	237.02	178.14	138.16	128.11	89.80	70.03
	Number of E 18-kip axles	553.55	354.78	537.86	460.44	391.97	590.71	464.33	399.51
	Dollars of transport cost	166.74	93.62	91.50	74.39	62.85	61.97	51.75	47.93
26/44	Average payload, lb.	9,069	17,358	18,233	24,347	31,289	33,945	48,339	61,710
	Number of vehicles required	441.06	230.44	219.38	164.29	127.84	117.84	82.75	64.82
	Number of E 18-kip axles	726.50	445.08	694.98	574.79	482.10	758.93	581.90	491.83
	Dollars of transport cost	157.19	88.77	86.19	70.29	59.95	59.35	50.24	47.15

227 percent. The 3-S2 vehicle would transmit to the pavement 3.77 E 18-kip axles per vehicle, while the 2-S1-2 combination would transmit to the pavement 6.44 E 18-kip axles per combination at the highest weight limitation studied (26/44-kip axles) and 1.05 and 1.38 E 18-kip axles per vehicle, respectively, at the lowest weight limitations studied (18/32 kips).

Table 14-8 indicates that at all five axle-weight levels the lowest cost of moving 2,000 tons of highway freight one mile is obtained through the use of the 3-S2-4. The most costly trailer combination is the 2-S1. The most costly of the eight classes of vehicle is the 2D single-unit truck.

C. Schemes 2, 3, and 4: Hauling 2,000 Tons of Freight in Fleets made up of Several Classes of Vehicles

Three hypothetical fleets (schemes 2, 3, and 4) composed of several classes of vehicles were envisaged for the purpose of transporting 2,000 tons of freight between two points one mile apart. The efficiency of these fleets is based upon both cube (cargo-volume capacity) and weight requirements and is forecast with respect to loaded and empty vehicle loadings observed at truck weighing stations in 1963.

For this study, each class of vehicle was assumed to travel empty 33 percent of the time; one-fourth loaded, from the standpoint of axle weights, 17 percent of the time; three-fourths loaded 30 percent of the time; and fully loaded only 20 percent of the time.

(1) Distribution of the 2,000 tons among the various vehicle classes

The shipping densities of cargo are the key factors in selecting the economical vehicle when both axle-weight limits and number and length of cargo bodies are considered. The 2-S1 combination under an 18/32-kip axle-weight limit will utilize its 2,262 cubic feet of usable capacity when loaded with commodities of density less than 11½ pounds per cubic foot (pcf). The 2,262 cubic feet is based on an exterior trailer length of 40 feet, height from pavement to exterior of roof of 13.5 feet, an exterior width of 96 inches, and a maximum inside cargo space height of 9.0 feet with an assumed inside loading height of 7.5 feet. Commodities weighing 11½ pcf or more must travel in 2-S1 combinations less than visibly fully loaded because of axle-weight limits.

Similarly, the 2-S2 combination cannot legally (under 18/32-kip axle limitations) travel with a visibly full load of commodities weighing more than about 16 pcf. The 3-S2 combination can legally travel with visibly full loads of commodities weighing up to 21 pcf but above that weight this vehicle must travel less than fully volume-loaded. See tables 14-10 and 14-11 for the maximum product densities for visibly fully loaded vehicles.

By increasing the axle-weight allowances from 18/32 to 26/44 kips, the cutoff points above which full cubage loads could not legally be carried would be raised from 11½ to 16½

Table 14-10.-- Scheme 2: Shipping density in pounds per cubic foot at which cargo can be stowed visibly fully loaded at various axle-weight limitations in highway vehicles with single cargo-body dimensions of 40-feet length and 96 inches width

Axle weight limits Single/tandem, kips		2-S1	2-S2	3-S2
18/32	Practical maximum gross vehicle weight, lb.	43,600	58,400	73,700
	Empty weight, lb.	17,400	22,070	26,370
	Maximum payload weight, lb.	26,200	36,330	47,330
	Shipping density, lb./cu.ft.	11.58	16.06	20.92
20/35	Stowage capacity, cu.ft.	48,000	63,700	80,000
	Empty weight, lb.	19,050	23,570	27,895
	Maximum payload weight, lb.	28,950	40,130	52,105
	Shipping density, lb./cu.ft.	12.80	17.74	23.03
22/38	Stowage capacity, cu.ft.	52,300	69,000	86,300
	Empty weight, lb.	20,500	24,970	29,320
	Maximum payload weight, lb.	31,800	44,030	56,980
	Shipping density, lb./cu.ft.	14.06	19.46	25.19
24/41	Stowage capacity, cu.ft.	56,500	74,300	92,600
	Empty weight, lb.	21,800	26,270	30,670
	Maximum payload weight, lb.	34,700	48,030	61,930
	Shipping density, lb./cu.ft	15.34	21.23	27.38
26/44	Stowage capacity, cu.ft.	60,600	79,600	98,900
	Empty weight, lb.	23,000	27,520	31,970
	Maximum payload weight, lb.	37,600	52,080	66,930
	Shipping density, lb./cu.ft.	16.62	23.02	29.59
	Stowage capacity, cu.ft.	2,262	2,262	2,262

Table 14-11. -- Shipping density in pounds per cubic foot at which cargo can be stowed visibly fully loaded at various axle-weight limits in highway vehicles with double cargo bodies with dimensions of 27 feet and 40 feet length and 96 inches width

Axle weight limit single/ tandem, kips		Scheme 3 27 feet long and 96 inches wide			Scheme 4 40 feet long and 96 inches wide		
		2-S1-2	2-S2-3	3-S2-4	2-S1-2	2-S2-3	3-S2-4
18/32	Practical maximum gross vehicle weight, lb.	80,700	109,300	138,000	80,700	109,300	138,000
	Empty weight, lb.	29,790	37,600	44,500	33,300	42,540	49,440
	Maximum payload weight, lb.	50,910	71,700	93,500	47,400	66,760	88,560
	Shipping density, lb./cu. ft.	16.80	23.66	30.86	10.48	14.76	19.58
20/35	Stowage capacity, cu. ft.	88,900	119,700	150,300	88,900	119,700	150,300
	Empty weight, lb.	33,065	40,325	47,425	36,575	45,265	52,365
	Maximum payload weight, lb.	55,835	79,375	102,875	52,325	74,435	97,935
	Shipping density, lb./cu. ft.	18.43	26.20	33.95	11.57	16.45	21.65
22/38	Stowage capacity, cu. ft.	97,100	130,100	162,600	97,100	130,100	162,600
	Empty weight, lb.	35,940	42,850	50,150	39,450	47,790	55,090
	Maximum payload weight, lb.	61,160	87,250	112,450	57,650	82,310	107,510
	Shipping density, lb./cu. ft.	20.18	28.80	37.11	12.74	18.19	23.76
24/41	Stowage capacity, cu. ft.	105,300	140,500	174,900	105,300	140,500	174,900
	Empty weight, lb.	38,515	45,225	52,725	42,025	50,165	57,665
	Maximum payload weight, lb.	66,785	95,275	122,175	63,275	90,335	117,235
	Shipping density, lb./cu. ft.	22.04	31.44	40.32	13.99	19.97	25.91
26/44	Stowage capacity, cu. ft.	113,500	150,900	187,200	113,500	150,900	187,200
	Empty weight, lb.	40,890	47,500	55,200	44,400	52,440	60,140
	Maximum payload weight, lb.	72,610	103,400	132,000	69,100	98,460	127,060
	Shipping density, lb./cu. ft.	23.96	34.13	43.56	15.27	21.76	28.09
	Stowage capacity, cu. ft.	3,030	3,030	3,030	4,524	4,524	4,524

Table 14-12. -- Distribution of 2,000 tons of payload by 5-pound shipping density groups and an estimate of the total cubage required to haul the 2,000 tons of payload

Shipping density, pcf	Percentage of total intercity freight in 1960 1/	Cumulative percentage of inter-city freight in 1960 1/	Distribution of 2,000 tons of highway freight (tons)	Cubage required for 2,000 tons of highway freight (cf)
5- 9.9	1.30	1.30	26.0	6,980
10- 14.9	3.15	4.45	63.0	10,120
15- 19.9	0.58	5.03	11.6	1,330
20- 24.9	1.71	6.74	34.2	3,047
25- 29.9	4.34	11.08	86.8	6,324
30- 34.9	3.79	14.87	75.8	4,672
35- 39.9	5.29	20.16	105.8	5,650
40- 44.9	9.25	29.41	185.0	8,716
45- 49.9	10.44	39.85	208.8	8,801
50- 54.9	5.34	45.19	106.8	4,072
55- 59.9	8.65	53.84	173.0	6,023
60- 64.9	0.11	53.95	2.2	70
65- 69.9	1.12	55.07	22.4	664
70- 74.9	0.48	55.55	9.6	265
80- 84.9	0.17	55.72	3.4	82
85- 89.9	0.03	55.75	0.6	14
90- 94.9	2.98	58.73	59.6	1,289
100-104.9	33.52	92.25	670.4	13,087
105-109.9	0.27	92.52	5.4	101
110-114.9	0.26	92.78	5.2	92
115-119.9	0.50	93.28	10.0	170
130-134.9	1.45	94.73	29.0	438
145-149.9	1.96	96.69	39.2	532
155-159.9	0.02	96.71	0.4	5
160-164.9	0.08	96.79	1.6	20
165-169.9	0.04	96.83	0.8	10
180-184.9	0.10	96.93	2.0	22
185-189.9	2.20	99.13	44.0	469
195-199.9	0.01	99.14	0.2	2
215-219.9	0.04	99.18	0.8	7
220-224.9	0.24	99.42	4.8	43
225-229.9	0.55	99.97	11.0	97
310-314.9	0.03	100.00	0.6	4
TOTAL	100.00		2,000.0	83,218

1/ Source: Based on Table 2 of report, "Intercity Freight Haulage, by Commodity, Shipping Density and Type of Transport, 1960," by Malcolm F. Kent, Highway Research Record 82, Highway Research Board.

pcf for the 2-S1 combination, from 16 to 23 pcf for the 2-S2, and from 21 to 29½ pcf for the 3-S2.

Table 14-12 indicates that on the basis of weight only, 1.30 percent of commodities moving by highway transport have shipping densities of less than 10 pcf; 4.45 percent, less than 15 pcf; 5.03 percent, less than 20 pcf; 6.74 percent, less than 25 pcf; and 11.08 percent, less than 30 pcf. Therefore, using the 3-S2 combination with a 40-foot body, slightly more than 5.03 percent of all commodities hauled, or only those of a density of less than 21 pcf, could be hauled as a visibly full load without exceeding an 18/32-kip axle-weight limit. Under an axle-weight limit of 26/44 kips, close to 11.08 percent of all commodities, or those of less than 30 pcf, could be hauled as visibly full loads without exceeding the axle-weight limits.

Scheme 2 is based on the use of vehicles with single cargo bodies. The proportion of the 2,000 tons of freight to be carried by each of the five vehicle classes affected by increases in axle-weight limits is based upon the results of the 1962 truck weight study. Because gross vehicle weight limitations have been raised in 19 States since 1962, the 3-S2 vehicle is now supplanting the 2-S2 vehicle. For this reason, it is assumed in this analysis that the vehicle-miles reported for the 2-S2 vehicle are indicative of the future 3-S2 travel and vice versa.

The vehicle classes and the proportion of the 2,000 tons assigned to each vehicle are as follows:

SCHEME 2

Vehicle class	Highway freight (Tons)	Percent
2D	220	11
3A	80	4
2-S1	140	7
2-S2	680	34
3-S2	880	44
	2,000	100

In a fleet with mixed single- and double-cargo bodies, the tonnage of cargo to be hauled will be divided between single- and double-cargo vehicles and combinations on the basis of transport requirements and economy. The vehicles with single-cargo bodies will not be entirely supplanted by the double-cargo vehicles, should the double-cargo combination be authorized where it is not now permitted.

The distribution of the 2,000 tons of freight among the vehicle classes, when 27-foot double-cargo-body combinations are included in the fleet, is based partly on vehicle class distribution in States allowing both single- and double-cargo-body vehicles and partly on experience in Michigan where both 7- and 9-axle and more combinations are found. The assumed distribution of the 2,000 tons to a fleet with 27-foot double-cargo combinations is as follows:

SCHEME 3

Vehicle class	Highway freight (Tons)	Percent
2D	220	11.0
3A	70	3.5
2-S1	130	6.5
2-S2	280	14.0
3-S2	300	15.0
2-S1-2	200	10.0
2-S2-3	400	20.0
3-S2-4	400	20.0
	2,000	100.0

In the above distribution, the single-unit trucks (2D and 3A) are assigned 14.5 percent of the total tonnage; the single-trailer combination vehicles (2-S1, 2-S2, and 3-S2), 35.5 percent; and the double-trailer combination vehicles (2-S1-2, 2-S2-3, and 3-S2-4), the remaining 50.0 percent. For the 2-S1 combination, there still is a need of commodities weighing up to 10 pcf, and for the 2-S2, commodities weighing $15\frac{1}{2}$ to $22\frac{1}{2}$ pcf.

The tons of cargo assigned to each vehicle type in this combined 40-foot single- and 40-foot double-cargo-body fleet are as follows:

SCHEME 4

Vehicle class	Highway freight (Tons)	Percent
2D	220	11.0
3A	70	3.5
2-S1	100	5.0
2-S2	220	11.0
3-S2	260	13.0
2-S1-2	230	11.5
2-S2-3	420	21.0
3-S2-4	480	24.0
	2,000	100.0

(2) Comparison of number of vehicles and E 18-kip axle applications

The number of vehicles necessary to carry the assigned tons of payload was obtained by dividing the total pounds of freight by the average payload per vehicle considering all degrees of loading from empty of full. For example, in scheme 2 the 12,249-pound average payload of the 2-S1, under single 18- and tandem 32-kip limitations, when divided into 140 tons, resulted in 22.86 2-S1 combination vehicles required to carry this assigned tonnage for the single-cargo-body fleet.

Table 14-13 shows that, for each vehicle class in schemes 2, 3 and 4, the number of vehicles needed decreases as the axle-weight limits increase. Also, it is evident that, although the number of vehicles required decreases, the E 18-kip factors for the heavier axle weight results in increased E 18-kip applications.

(3) Comparison of vehicle operating costs

For scheme 2, for which single-cargo-body vehicles were used in the transport of 2,000 tons of freight at the 18/32-kip axle-weight limits, total operating costs were found to be about 14 percent higher than for scheme 3, in which double-cargo-body combinations 40-feet in length were used. As shown in table 14-13, at the 18/32-kip axle-weight limits, the cost per mile to move 2,000 tons of highway freight is $97.36 for the

Table 14-13. -- Number of vehicles, dollars of transport cost, and Σ 18-kip axles necessary to move 2,000 tons of freight at various axle-weight limits for schemes 2, 3, and 4.

Vehicle class	Payload (tons)	18/32 kip axles			20/35 kip axles			22/38 kip axles			24/41 kip axles			26/44 kip axles		
		Number of vehicles	Transport cost (dollars)	Σ 18-kip axles	Number of vehicles	Transport cost (dollars)	Σ 18-kip axles	Number of vehicles	Transport cost (dollars)	Σ 18-kip axles	Number of vehicles	Transport cost (dollars)	Σ 18-kip axles	Number of vehicles	Transport cost (dollars)	Σ 18-kip axles
SCHEME 2 *																
2D	220	58.16	$19.91	19.65	56.09	$19.39	30.30	52.93	$18.48	43.38	49.58	$17.49	59.33	41.98	$14.96	70.76
3A	80	13.18	4.79	7.01	12.17	4.48	9.40	11.24	4.20	12.23	10.42	3.95	15.36	9.70	3.74	19.17
2-S1	140	22.86	8.37	15.90	20.69	7.71	22.12	18.83	7.14	30.61	17.26	6.66	39.84	15.93	6.26	51.21
2-S2	680	80.08	31.17	70.78	72.49	28.87	94.91	66.07	26.94	123.15	60.57	25.29	156.52	55.86	23.90	195.42
3-S2	880	79.54	33.12	83.34	72.25	30.97	109.08	66.07	29.17	137.11	60.79	27.65	172.50	56.25	26.38	212.70
Total	2,000	253.82	97.36	196.68	233.69	91.42	265.81	215.14	85.93	346.48	198.62	81.04	443.55	179.72	75.24	548.70
SCHEME 3 **																
2D	220	58.16	19.91	19.65	56.09	19.39	30.30	52.93	18.48	43.38	49.58	17.49	59.33	41.98	14.96	70.76
3A	70	11.54	4.19	6.14	10.65	3.92	8.24	9.84	3.68	10.70	9.12	3.46	13.45	8.49	3.27	16.80
2-S1	130	21.23	7.77	14.78	19.21	7.16	20.53	17.49	6.63	28.43	16.03	6.19	37.04	14.79	5.81	47.62
2-S2	280	32.97	12.83	29.13	29.85	11.89	39.08	27.21	11.09	50.69	24.94	10.41	64.47	23.00	9.84	80.47
3-S2	300	27.12	11.29	28.41	24.63	10.56	37.16	22.52	9.94	46.71	20.72	9.43	58.77	19.18	8.99	72.35
2-S1-2	200	16.81	7.23	23.23	15.32	6.85	33.01	13.99	6.50	44.96	12.81	6.20	59.03	11.78	5.93	75.91
2-S2-3	400	23.86	11.77	41.77	21.56	11.20	55.99	19.61	10.73	72.62	17.96	10.35	92.85	16.55	10.05	116.43
3-S2-4	400	18.30	10.41	37.93	16.63	10.07	49.76	15.22	9.80	63.88	14.01	9.59	79.86	12.96	9.43	98.34
Total	2,000	209.99	85.40	201.04	193.94	81.04	274.07	178.81	76.85	361.37	165.17	73.12	464.80	148.73	68.28	578.68
SCHEME 4 ***																
2D	220	58.16	19.91	19.65	56.09	19.39	30.30	52.93	18.48	43.38	49.58	17.49	59.33	41.98	14.96	70.76
3A	70	11.54	4.19	6.14	10.65	3.92	8.24	9.84	3.68	10.70	9.12	3.46	13.45	8.49	3.27	16.80
2-S1	100	16.33	5.98	11.35	14.78	5.51	15.81	13.45	5.10	21.84	12.33	4.76	28.43	11.38	4.47	36.64
2-S2	220	25.91	10.08	22.89	23.45	9.34	30.69	21.38	8.72	39.85	19.60	8.18	50.66	18.07	7.73	63.28
3-S2	260	23.50	9.79	24.62	21.35	9.15	32.22	19.52	8.62	40.48	17.96	8.17	50.94	16.62	7.79	62.65
2-S1-2	230	20.76	8.93	29.75	18.80	8.40	41.88	17.07	7.93	56.56	15.55	7.52	73.68	14.24	7.17	93.96
2-S2-3	420	26.91	13.28	49.28	24.14	12.54	67.36	21.83	11.94	83.60	19.89	11.46	105.96	18.25	11.08	131.88
3-S2-4	480	23.18	13.19	46.03	20.97	12.69	64.45	19.10	12.30	82.10	17.52	11.99	101.62	16.16	11.76	125.06
Total	2,000	206.29	$85.35	209.71	190.23	$80.94	290.95	175.12	$76.77	378.51	161.55	$73.03	484.07	145.19	$68.23	601.03

* SCHEME 2 - Using single unit trucks and 40-foot semitrailers at 55 feet maximum length.

** SCHEME 3 - Using single unit trucks, 40-foot semitrailers, and double 27-foot trailers at 65 feet maximum length.

*** SCHEME 4 - Using single unit trucks, 40-foot semitrailers, and double 40-foot trailers at 65 feet maximum length.

single-cargo-body fleet, $85.40 for the fleet with 27-foot double trailers, $85.35 for the fleet with 40-foot double trailers. Similar costs for these three fleets under the 26/44-kip restrictions are $75.24, $68.28, and $60.23, respectively. This reduction in motor vehicle operating cost of approximately 23 percent for the three fleets at the 26/44-kip axle-weight limits results from carrying the same payload in fewer vehicles at the 26/44-kip axle-weight limit than are required at the 18/32-kip axle-weight limit.

3. MARGINAL AXLE-WEIGHT LIMITS BASED ON ECONOMY OF TRANSPORTING 2,000 TONS OF PAYLOAD

The analyses of the economy of axle-weight limits, as presented in Chapter 10, indicate that there is overall transportation economy in axle-weight limits above the 26/44-kip limit used in these analyses. It is desirable, therefore, to extend the analyses to still higher axle-weight limits. In order to gain some indication of the axle-weight limits above which no further economy may be expected, the 2,000 ton payload study was extended to 60/95-kip limits using a hypothetical fleet.

A. Concepts and Procedures

As a first approach to determining the marginal limits of vehicle axle weights above which no further transportation economy could be achieved, the 2,000-ton study described in the preceding section was extended to higher axle-weight limits.

The results apply only to the primary rural system in the East North Central census division, which was chosen for analysis.

The analysis is based on hauling 2,000 tons of payload one mile on a newly constructed highway. The axle-weight limits used are as follows:

Single/tandem, pounds	Single/tandem, pounds
18,000/32,000	32,000/53,000
20,000/35,000	36,000/59,000
22,000/38,000	40,000/65,000
24,000/41,000	44,000/71,000
26,000/44,000	48,000/77,000
28,000/47,000	52,000/83,000
	60,000/95,000

The distribution of payload among the classes of vehicles in the scheme is the same as previously given in table 14-13. The loading distribution between empty and full payload, also is the same as stated on page 14-21. The vehicle empty weights and practical maximum gross weights were taken from tables 14-4 and 14-5. The average payloads per vehicle for each class of vehicle and the three schemes of fleet composition are given in table 14-14.

The E 18-kip axle applications, highway costs, and maintenance costs were calculated according to the procedure developed in Method 1. Table 14-17 gives the motor vehicle operating costs per vehicle-mile for the axle-weight limits of 28/47 kips and above.

Table 14-14.--Average payloads per vehicle for the axle-weight limits of 28/47 kips and above.

Vehicle classification	Single/tandem axle weight limits - kips							
	28/47	32/53	36/59	40/65	44/77	48/77	52/83	60/95
				Scheme 2				
2D	10,135	11,725	13,455	15,278	17,148	19,065	20,993	24,955
3A	17,690	20,121	22,646	25,170	27,741	30,406	33,118	38,541
2-S1	18,980	21,832	24,731	27,676	30,668	33,707	36,792	43,033
2-S2	26,269	30,163	34,109	38,101	42,140	46,226	50,359	58,727
3-S2	36,651	38,419	43,234	48,096	53,005	57,961	62,963	73,037
				Scheme 3				
2D	10,135	11,725	13,455	15,278	17,148	19,065	20,993	24,955
3A	17,690	20,121	22,646	25,170	27,741	30,406	33,118	38,541
2-S1	18,980	21,832	24,731	27,676	30,668	33,707	36,792	43,033
2-S2	26,269	30,163	34,109	38,101	42,140	46,226	50,359	58,727
3-S2	33,651	38,419	43,234	48,096	53,005	57,961	62,963	73,037
2-S1-2	36,762	42,489	48,309	54,223	60,230	66,331	72,526	85,055
2-S2-3	52,185	59,969	67,846	76,284	84,816	93,442	102,160	114,128
3-S2-4	66,350	75,723	85,190	94,751	104,404	114,152	123,993	143,815
				Scheme 4				
2D	10,135	11,725	13,455	15,278	17,148	19,065	20,993	24,955
3A	17,690	20,121	22,646	25,170	27,741	30,406	33,118	38,541
2-S1	18,980	21,832	24,731	27,676	30,668	33,707	36,792	43,033
2-S2	26,629	30,163	34,109	38,101	42,140	46,226	50,359	58,727
3-S2	33,651	38,419	43,234	48,096	53,005	57,961	62,963	73,037
2-S1-2	35,121	40,848	46,668	52,582	58,589	64,690	70,885	83,414
2-S2-3	49,875	57,659	65,537	73,975	82,507	91,132	99,851	111,819
3-S2-4	64,041	73,414	82,881	92,441	102,095	111,842	121,683	141,505

Table 14-17.-Loaded gross weight and operating cost per mile for selected vehicle classes

Vehicle class	Axle weight limit, kips, single/tandem 28/47	32/53	36/59	40/65	44/71	48/77	52/83	60/95
A. 80 percent of maximum practical gross vehicle weight kips = loaded gross weight								
2D	31.52	36.00	40.48	44.96	49.44	53.92	58.40	67.36
3A	47.68	53.44	59.20	64.96	70.72	76.48	82.24	93.76
2-S1	51.68	58.24	64.80	71.36	77.92	84.48	91.04	104.16
2-S2	67.92	76.40	84.88	93.36	101.84	110.32	118.80	135.76
3-S2	84.16	94.24	104.32	114.40	124.48	134.56	144.64	164.80
2-S1-2	97.36	110.48	123.60	136.72	149.84	162.96	176.08	202.32
2-S2-3	129.20	146.00	162.80	179.60	196.40	213.20	230.00	263.60
3-S2-4	159.60	179.28	198.96	218.64	238.32	258.00	277.68	317.04
B. Operating cost, cents per vehicle-mile								
2D	36.021	36.819	37.664	38.556	39.495	40.479	41.511	43.715
3A	39.120	40.372	41.701	43.106	44.590	46.150	47.788	51.295
2-S1	39.981	41.474	43.066	44.760	46.553	48.446	50.439	54.726
2-S2	43.859	46.128	48.564	51.168	53.939	56.877	59.983	66.697
3-S2	48.351	51.448	54.781	58.351	62.157	66.200	70.479	79.748
2-S1-2	52.454	56.934	61.815	67.097	72.779	78.863	85.346	99.516
2-S2-3	64.021	71.075	78.786	87.154	96.179	105.861	116.200	138.850
3-S2-4	77.267	86.989	97.612	109.137	121.564	134.892	149.122	180.287

B. Results of the Analysis

Table 14-18 sets forth for each scheme the number of vehicles by class, the total motor vehicle transport cost, and the number of E 18-kip axle applications for each of eight levels of axle-weight limit. A general observation from the table is that, as the axle-weight limit moves upward from 28/47 kips to 60/95 kips, the number of vehicles is reduced to about half the initial number, and the E 18-kip axles are increased about 10 times.

The benefit-cost ratios and the basic highway and motor vehicle costs are given in table 14-19 for the full range of axle-weight limits from 18/32 kips to 60/95 kips. For all three schemes, the incremental benefit-cost ratios decrease with increasing axle-weight limits. The marginal axle-weight limits are about 56/89, 52/83, and 52/83, respectively, for the three schemes. The ratios are plotted in figure 14-1.

As mentioned at the beginning of this section, the analysis applies to hauling 2,000 tons of payload one mile in hypothetical fleets of vehicles under the highway costs pertaining to the primary rural system in the East North Central census division. Since the overall economy of increased axle-weight limits depends upon the number of trucks (ADT) and the fleet composition by vehicle class, this type of analysis would lead to different results with smaller or greater total numbers of tons of payload to transport. The answers, however, are

Table 14-18. -- Number of vehicles, transport cost, and Σ 18-kip axles for hauling 2,000 tons of payload one mile on system 3, primary rural, East North Central census division - rigid pavement

Sheet 1 of 3

Vehicle classification and tons carried	Scheme 2	Single/tandem axle weight limits, kips							
		28/47	32/53	36/59	40/65	44/71	48/77	52/83	60/95
2D 220	Number of vehicles	43.41	37.53	32.70	28.80	25.66	23.08	20.96	17.63
	Transport cost - $	15.64	13.82	12.32	11.10	10.13	9.34	8.70	7.71
	Σ 18-kip axles	100.06	151.50	213.41	297.64	398.46	521.97	667.66	1,047.15
3A 80	Number of vehicles	9.04	7.95	7.07	6.36	5.77	5.26	4.83	4.15
	Transport cost - $	3.54	3.21	2.95	2.74	2.57	2.43	2.31	2.13
	Σ 18-kip axles	23.40	33.56	46.74	63.00	83.28	107.71	137.34	212.36
2-S1 140	Number of vehicles	14.75	12.83	11.32	10.12	9.13	8.31	7.61	6.51
	Transport cost - $	5.90	5.32	4.88	4.53	4.25	4.03	3.84	3.56
	Σ 18-kip axles	64.22	97.63	139.48	194.45	266.68	350.68	453.91	727.50
2-S2 680	Number of vehicles	51.77	45.09	39.87	35.69	32.27	29.42	27.01	23.16
	Transport cost - $	22.70	20.80	19.36	18.26	17.41	16.73	16.20	15.45
	Σ 18-kip axles	242.03	353.82	499.22	688.29	923.34	1,206.11	1,551.12	2,459.01
3-S2 880	Number of vehicles	52.03	45.81	40.71	36.59	33.20	30.36	27.95	24.10
	Transport cost - $	25.29	23.57	22.30	21.35	20.64	20.10	19.70	19.22
	Σ 18-kip axles	258.15	362.20	510.00	689.27	913.72	1,190.27	1,508.81	2,365.88
Total 2,000	Number of vehicles	171.27	149.21	131.67	117.56	106.03	96.43	88.36	75.55
	Transport cost - $	73.07	66.72	61.81	57.98	55.00	52.63	50.75	48.07
	Σ 18-kip axles	687.86	998.71	1,408.51	1,932.65	2,585.48	3,376.74	4,318.84	6,811.90

Table 14-18. -- Number of vehicles, transport cost, and Σ 18-kip axles for hauling 2,000 tons of payload one mile on system 3, primary rural, East North Central census division - rigid pavement

Sheet 2 of 3

Vehicle classification and tons carried	Scheme 3	Single/tandem axle weight limits, kips							
		28/47	32/53	36/59	40/65	44/71	48/77	52/83	60/95
2D	Number of vehicles	43.41	37.53	32.70	28.80	25.66	23.08	20.96	17.63
220	Transport cost - $	15.64	13.82	12.32	11.10	10.13	9.34	8.70	7.71
	Σ 18-kip axles	100.06	151.50	213.41	297.64	398.46	521.97	667.66	1,047.15
3A	Number of vehicles	7.91	6.96	6.18	5.56	5.05	4.60	4.23	3.63
70	Transport cost - $	3.09	2.81	2.58	2.40	2.25	2.12	2.02	1.86
	Σ 18-kip axles	20.45	29.36	40.81	55.08	72.97	94.27	119.43	185.06
2-S1	Number of vehicles	13.70	11.91	10.51	9.39	8.48	7.71	7.07	6.04
130	Transport cost - $	5.48	4.94	4.53	4.20	3.95	3.74	3.57	3.31
	Σ 18-kip axles	59.67	90.46	129.48	180.74	247.56	324.90	423.32	676.50
2-S2	Number of vehicles	21.32	18.57	16.42	14.70	13.29	12.11	11.12	9.54
280	Transport cost - $	9.35	8.57	7.97	7.52	7.17	6.89	6.67	6.36
	Σ 18-kip axles	99.60	145.58	205.57	283.42	380.71	496.21	638.34	1,013.55
3-S2	Number of vehicles	17.83	15.62	13.88	12.48	11.32	10.35	9.53	8.22
300	Transport cost - $	8.62	8.04	7.60	7.28	7.04	6.85	6.72	6.56
	Σ 18-kip axles	88.07	123.46	173.98	235.19	311.31	405.62	461.16	806.06
2-S1-2	Number of vehicles	10.88	9.41	8.28	7.38	6.64	6.03	5.52	4.70
200	Transport cost - $	5.71	5.36	5.12	4.95	4.83	4.76	4.71	4.68
	Σ 18-kip axles	94.68	141.89	205.66	286.43	388.33	519.13	660.96	1,056.76
2-S2-3	Number of vehicles	15.33	13.34	11.79	10.49	9.43	8.56	7.83	7.01
400	Transport cost - $	9.81	9.48	9.29	9.14	9.07	9.06	9.10	9.73
	Σ 18-kip axles	142.27	206.54	295.20	400.42	529.85	690.19	885.87	1,266.99
3-S2-4	Number of vehicles	12.06	10.56	9.39	8.44	7.66	7.01	6.45	5.56
400	Transport cost - $	9.32	9.19	9.17	9.21	9.31	9.46	9.62	10.02
	Σ 18-kip axles	120.41	170.80	238.81	325.27	427.53	560.22	710.57	1,118.42
Total	Number of vehicles	142.44	123.90	109.15	97.24	87.53	79.45	72.71	62.33
2,000	Transport cost - $	67.02	62.21	58.58	55.80	53.75	52.22	51.11	50.23
	Σ 18-kip axles	725.21	1,059.59	1,502.92	2,064.19	2,756.72	3,612.51	4,567.31	7,170.49

Table 14-18. -- Number of vehicles, transport cost, and Σ 18-kip axles for hauling 2,000 tons of payload one mile on system 3, primary rural, East North Central census division - rigid pavement

Sheet 3 of 3

Vehicle classification and tons carried	Scheme 4	Single/tandem axle weight limits, kips							
		28/47	32/53	36/59	40/65	44/71	48/77	52/83	60/95
2D 220	Number of vehicles	43.41	37.53	32.70	28.80	25.66	23.08	20.96	17.63
	Transport cost - $	15.64	13.82	12.32	11.10	10.13	9.34	8.70	7.71
	Σ 18-kip axles	100.06	151.50	213.41	297.64	398.46	521.97	667.66	1,047.15
3A 70	Number of vehicles	7.91	6.96	6.18	5.56	5.05	4.60	4.23	3.63
	Transport cost - $	3.09	2.81	2.58	2.40	2.25	2.12	2.02	1.86
	Σ 18-kip axles	20.45	29.36	40.81	55.09	72.97	94.27	119.43	185.06
2-S1 100	Number of vehicles	10.54	9.16	8.09	7.23	6.52	5.93	5.44	4.65
	Transport cost - $	4.21	3.80	3.48	3.24	3.04	2.87	2.74	2.54
	Σ 18-kip axles	45.92	69.60	99.50	138.69	189.92	249.45	325.12	521.01
2-S2 220	Number of vehicles	16.52	14.59	12.90	11.55	10.44	9.52	8.74	7.49
	Transport cost - $	7.25	6.73	6.26	5.91	5.63	5.41	5.24	5.00
	Σ 18-kip axles	77.17	114.54	161.58	222.79	298.95	390.06	502.36	796.42
3-S2 260	Number of vehicles	15.45	13.53	12.03	10.81	9.81	8.97	8.26	7.12
	Transport cost - $	7.47	6.96	6.59	6.31	6.10	5.94	5.82	5.68
	Σ 18-kip axles	76.29	107.05	150.48	203.40	269.73	352.44	445.56	698.06
2-S1-2 230	Number of vehicles	13.10	11.26	9.86	8.75	7.85	7.11	6.49	5.51
	Transport cost - $	6.87	6.41	6.09	5.87	5.71	5.61	5.54	5.48
	Σ 18-kip axles	116.48	174.44	230.79	343.44	466.12	616.65	787.25	1,247.19
2-S2-3 420	Number of vehicles	16.84	14.57	12.82	11.36	10.18	9.22	8.41	7.51
	Transport cost - $	10.78	10.36	10.10	9.90	9.79	9.76	9.77	10.43
	Σ 18-kip axles	159.97	231.01	326.08	439.73	572.97	752.17	959.04	1,365.08
3-S2-4 480	Number of vehicles	14.99	13.08	11.58	10.38	9.40	8.58	7.89	6.78
	Transport cost - $	11.58	11.38	11.30	11.33	11.43	11.57	11.77	12.22
	Σ 18-kip axles	152.56	215.15	298.46	404.97	530.62	693.76	878.62	1,378.09
Total 2,000	Number of vehicles	138.76	111.52	106.16	94.44	84.91	77.01	70.42	60.32
	Transport cost - $	66.89	62.27	58.72	56.06	54.08	52.62	51.60	50.92
	Σ 18-kip axles	748.90	1,092.65	1,521.11	2,105.75	2,799.74	3,670.77	4,685.04	7,238.06

Table 14-19. -- Analysis of the marginal maximum axle-weight limits based on hauling 2,000 tons of freight over a mile of 4-lane rigid pavement, primary rural highway system: East North Central census division

	Single/tandem axle weight limits, kips												
	18/32	20/35	22/38	24/41	26/44	28/47	32/53	36/59	40/65	44/71	48/77	52/83	60/95
SCHEME 2: Single unit trucks and 40-foot semitrailers at 55-foot maximum length													
1. Construction cost/mile													
a. Pavement and shoulder	183,300	187,600	191,300	195,000	198,400	201,800	207,800	213,850	219,500	225,300	230,800	236,000	247,400
b. Bridge structures	28,526	28,898	29,231	29,536	29,821	30,069	30,478	30,859	31,221	31,564	31,897	32,231	32,897
c. Grading and drainage	101,056	101,136	101,211	101,283	101,353	101,425	101,551	101,680	101,804	101,928	102,039	102,145	102,360
d. Total construction cost	312,882	317,364	321,742	325,819	329,574	333,294	339,829	346,389	352,525	358,792	364,736	370,376	382,657
2. Equivalent uniform annual cost													
a. Construction cost *	27,279	27,669	28,051	28,407	28,734	29,058	29,627	30,200	30,735	31,281	31,800	32,291	33,362
b. Highway maintenance	506	530	554	575	597	619	657	696	734	772	805	837	750
c. Bridge maintenance	11	15	19	22	25	27	32	36	39	43	46	50	57
d. Total equivalent uniform annual cost	27,796	28,214	28,624	29,004	29,356	29,704	30,316	30,923	31,508	32,096	32,651	33,178	34,169
3. Incremental annual highway cost	-	418	410	380	352	348	612	607	598	588	555	519	991
4. Annual motor vehicle operating cost	35,536	33,368	31,364	29,580	28,053	26.671	24,353	22,561	21,163	20,075	19,210	18,524	17,546
5. Decremental annual vehicle cost	-	2,168	2,004	1,784	1,527	1,382	2,318	1,792	1,398	1,088	865	686	978
6. Benefit-cost ratio		5.19	4.97	4.69	4.34	3.97	3.79	2.95	2.33	1.85	1.56	1.32	0.98
SCHEME 3: Single unit trucks, 40-foot semitrailers, and double 27-foot trailers at 65-foot maximum length													
1. Construction cost													
a. Pavement and shoulder	183,800	187,900	192,000	195,700	199,200	202,700	208,800	214,800	220,800	226,800	232,200	237,100	247,700
b. Bridge structures	28,526	28,898	29,231	29,536	29,821	30,069	30,478	30,859	31,221	31,564	31,897	32,231	32,897
c. Grading and drainage	101,056	101,142	101,214	101,292	101,362	101,437	101,571	101,700	101,824	101,948	102,062	102,162	102,380
d. Total equivalent uniform annual cost	313,382	317,940	322,445	326,528	330,383	334,206	340,849	347,359	353,845	360,312	366,159	371,493	382,977
2. Equivalent uniform annual cost													
a. Construction cost *	27,322	27,720	28,112	28,468	28,804	29,138	29,719	30,284	30,850	31,414	31,924	32,389	33,390
b. Highway maintenance	506	532	554	577	598	621	662	701	739	776	810	840	905
c. Bridge maintenance	11	15	19	22	25	27	32	36	39	43	46	50	57
d. Total equivalent uniform annual cost	27,839	28,267	28,685	29,067	29,427	29,786	30,413	31,021	31,628	32,233	32,780	33,279	34,352
3. Incremental annual highway cost	-	428	418	382	360	359	627	608	607	605	547	499	1,073
4. Annual motor vehicle operating cost	31,171	29,580	28,050	26,689	25,521	24,462	22,707	21,382	20,367	19,619	19,060	18,655	18,334
5. Decremental annual vehicle cost	-	1,591	1,530	1,361	1,168	1,059	1,755	1,325	1,015	748	559	405	321
6. Benefit-cost ratio		3.71	3.66	3.56	3.24	2.95	2.80	2.18	1.67	1.24	1.02	0.81	0.30
SCHEME 4: Single unit trucks, 40-foot semitrailers, and 40-foot trailers at 100-foot maximum length													
1. Construction cost													
a. Pavement and shoulder	184,600	188,700	192,800	196,300	199,900	203,300	209,400	215,300	221,200	227,100	232,500	237,600	248,000
b. Bridge structures	28,526	28,898	29,231	29,536	29,821	30.069	30,478	30,859	31,221	31,564	31,897	32,231	32,897
c. Grading and drainage	101,056	101,150	101,222	101,297	101,364	101,439	101,573	101,697	101,824	101,946	102,060	102,166	102,378
d. Total equivalent uniform annual cost	314,182	318,748	323,253	327,133	331,085	334,808	341,451	347,856	354,245	360,610	366,457	371,997	383,275
2. Equivalent uniform annual cost													
a. Construction cost *	27,392	27,790	28,183	28,521	28,866	29,190	29,769	30,328	30,885	31,440	31,950	32,433	33,416
b. Highway maintenance	506	534	556	579	599	622	662	699	738	774	808	839	903
c. Bridge maintenance	11	15	19	22	25	27	32	36	39	43	46	50	57
d. Total equivalent uniform annual cost	27,909	28,339	28,758	29,122	29,490	29,839	30,463	31,063	31,662	32,257	32,804	33,322	34,376
3. Incremental annual highway cost	-	430	419	382	368	349	623	600	599	595	547	518	1,054
4. Annual motor vehicle highway cost	31,153	29,543	28,021	26,656	25,475	24,415	22,729	21,433	20,462	19,739	19,206	18,834	18,586
5. Decremental annual vehicle cost	-	1,610	1,522	1,365	1,181	1,060	1,686	1,296	971	723	533	372	248
6. Benefit-cost ratio		3.74	3.63	3.57	3.21	3.04	2.71	2.16	1.62	1.22	0.97	0.72	0.236

* Based on 6% per annum and 20 years (crf = 0.087185)

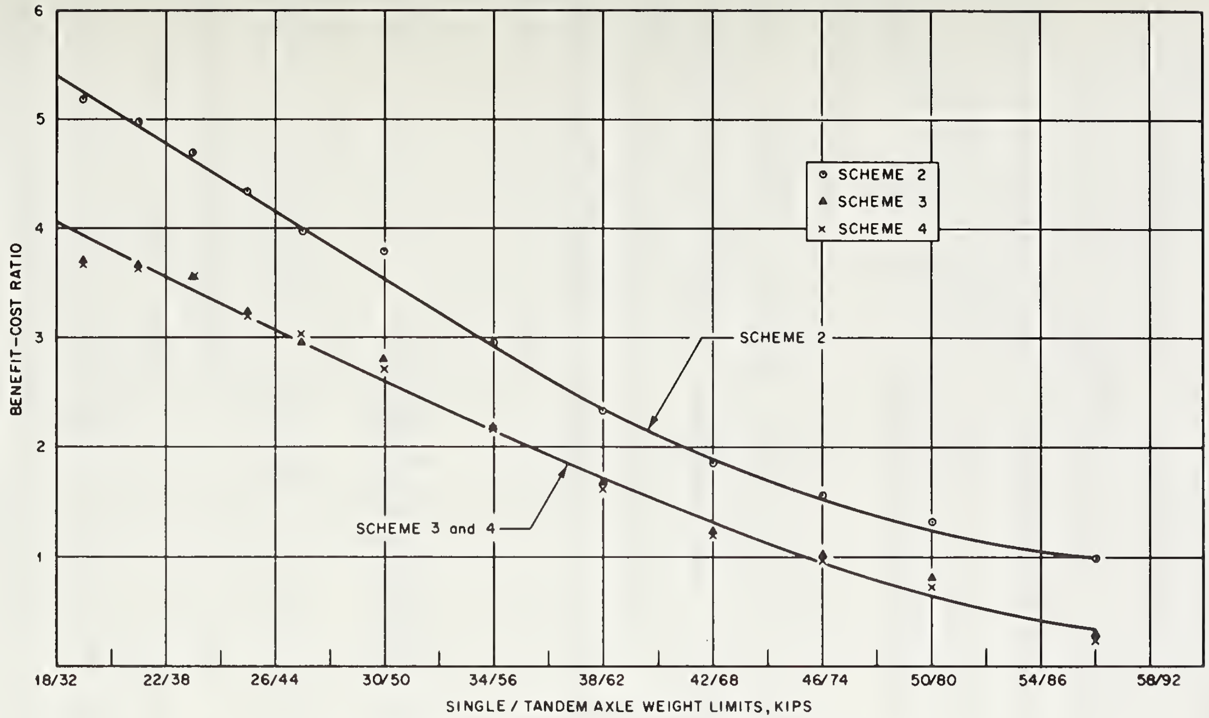

FIGURE 14-1. INCREMENTAL BENEFIT-COST RATIOS RELATED TO THE AXLE-WEIGHT MAXIMUM LIMITS AS CALCULATED FOR THE TRANSPORT OF 2,000 TONS OF PAYLOAD ON THE PRIMARY RURAL SYSTEM OF THE EAST NORTH CENTRAL CENSUS DIVISION; RIGID PAVEMENT AND A 20-YEAR ANALYSIS PERIOD.

helpful in gaining some insight into the ultimate limits of axle weight beyond which no further economy could be expected.

Attention is called to table 14-5 giving the practical maximum gross vehicle weights for each class of vehicle for axle-weight limits up to 60/95 kips. The highest gross vehicle weight in this table for axle-weight limits of 52/83 kips is 347.1 kips for the 3-S2-4 combination, or well above the gross vehicle weight of 225 kips, the point at which the trucking costs in cents per payload ton-mile cease to decrease. However, because all trucks do not move fully loaded as to weight and because, in a total fleet of several classes of vehicles, many vehicles would have far lower practical maximum gross weights than would the 3-S2-4, gross weights above the maximum for the limit of transport economy could prove economical in the total fleet of vehicles.

4. MARGINAL GROSS WEIGHT LIMITS BASED ON ECONOMY OF TRANSPORTING 2,000 TONS OF PAYLOAD

The preceding Section 3 attempts to determine the upper axle-weight limits beyond which no further transportation economy is to be expected. Economy is based upon the highway costs combined with motor vehicle operating costs. It is logical to determine as well the ultimate, or marginal, limits of gross vehicle weight, or that point where no further transport economy would result from further increases in gross vehicle weight.

A. Concepts and Procedure

Higher gross vehicle weights may be obtained by adding axles to the vehicle combination without increasing the maximum limits of axle weight. The adding of axles can be achieved by adding trailers to a chosen basic power tractor. Thus, the 2-S1 class of tractor-semitrailer could be successively increased in total gross combination weight by adding a second, third, fourth, and sixth trailer. This is the process followed, using the 2-S1, 2-S2, and 3-S2 semitrailer combinations as basic vehicles.

Unlike the analysis for the marginal axle-weight limit, the marginal gross vehicle-weight limit cannot be achieved considering the highway cost. This statement is true because when the axle-weight limits are held constant and the gross vehicle weight increased by adding trailers, there is no appreciable increase in the highway cost. In fact, in most of the cases tried, the highway cost actually decreased as the gross combination weight of the vehicle increased. Consequently, the marginal gross vehicle weight has been determined without reference to highway cost.

Essentially, the marginal gross vehicle weight is simply that gross vehicle weight, or that loaded gross vehicle weight, at which the cost of transporting goods reaches a minimum in cents per ton-mile of payload. This marginal loaded gross weight is given by Hoy Stevens [1] as approximately 180,000 pounds, which would correspond to a practical maximun gross vehicle weight of 225,000 pounds, based upon an 80-percent ratio of loaded gross weight to practical maximum gross vehicle weight.

B. Results of the Analysis for Marginal Gross Vehicle Weight

Figure 14-2 gives the transport cost in cents per payload ton-mile for the 2-S1, 2-S2, and 3-S2 vehicle classes with successive numbers of trailers up to gross vehicle combination weights of about 400,000 pounds expressed in terms of the practical maximum gross weight based upon the 18/32-kip single/tandem axle-weight limits. Curves based upon the Stevens 33-67 percent payload distribution are also given. It should be noticed that the difference between the Stevens payload distribution and the 33-17-30-20 percent distribution gives a decidely lower cost in cents per payload ton-mile for the 33-67 percent distribution. This would be expected, because the number of trips to haul 2,000 pounds would be fewer with the 33-67 distribution than with the 33-17-30-20 distribution.

The analysis for the marginal axle-weight limits indicated that they were about 52/83 kips single/tandem axle-

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1/ Hoy Stevens, Line-Haul Trucking Cost Upgraded, 1964, Highway Research Record No. 127, Highway Research Board, National Research Council, 1966, p. 19.

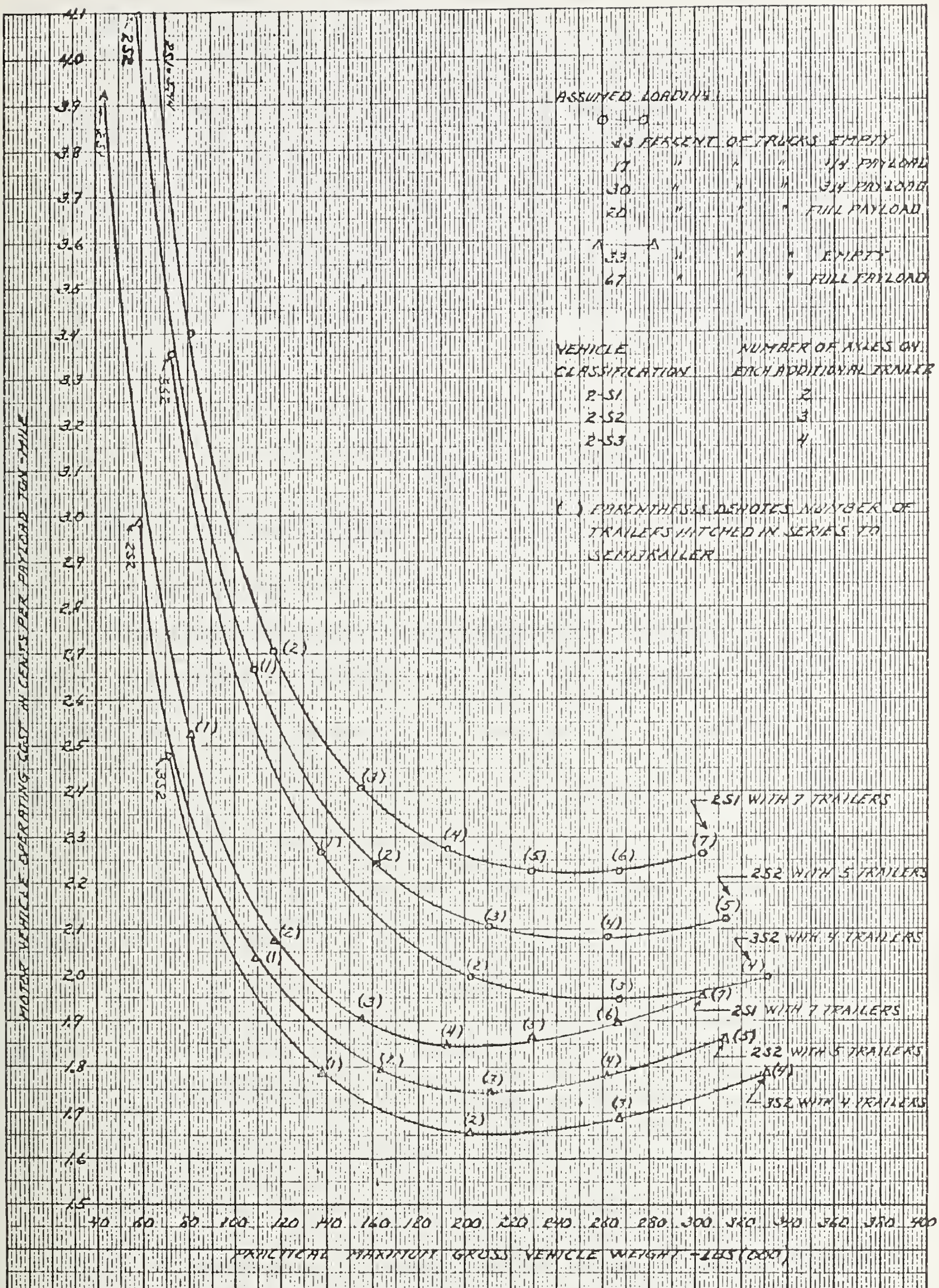

FIGURE 14-2 MOTOR VEHICLE OPERATING COST PER PAYLOAD TON-MILE VERSUS PRACTICAL MAXIMUM GROSS WEIGHT

weight limits. If the marginal axle weight found in that study is plotted in terms of gross vehicle weight, there is indication that the marginal practical maximum gross vehicle weight would be about 314,000 pounds, somewhat higher than was found in the marginal gross weight study. In any case, both the marginal axle weight and the marginal gross vehicle weight are appreciably higher than are apt to become legal in the foreseeable future.

C. Concluding Analysis with Respect to Marginal Gross Vehicle Weight

It is to be expected that intercity highway freight carriers will continue to find that the use of several classes of vehicles is desirable as a means of getting the most efficient operation in hauling different commodities different distances. Therefore, a specific marginal gross vehicle weight for the heaviest probable single class of vehicle to be used in a fleet would not indicate that such marginal gross vehicle weight would be attained by each separate class of vehicles within the fleet, or that it would not be an advantage to load higher than the marginal limit. It probably would be true that, because of the dropping off and picking up of trailers en route and other characteristics of transport operation, the trucking industry would find it advantageous on certain trips to start with an initial gross vehicle weight that is higher than the marginal gross vehicle weight, since there would be no significant increase in cost per payload ton-mile.

5. MARGINAL ADT FOR ECONOMY OF INCREASED AXLE-WEIGHT LIMITS

Because the pavement design depth is a function of the number of E 18-kip axle applications and the number of axle applications is a direction function of ADT, it is reasonable to expect that the economy (benefit-cost ratio) of increased axle-weight limits would vary with the change in ADT. The following study of the marginal ADT for economy of increased axle-weight limits shows that there is a minimum ADT below which the benefit-cost ratio is less than 1.0, and that there appears to be no upper limit to economy as ADT increases.

A. Scope of Study

An examination of the benefit-cost ratios resulting from Methods 1, 1-M, 2, and 3 discloses that, in general, lower ratios will be obtained with lower ADT. A positive conclusion is not readily apparent, because traffic composition, pavement design criteria, construction prices, and other factors besides ADT vary among highway systems and census divisions. Therefore, a study of marginal economical ADT was made for each of the 10 census divisions and each of the six highway systems. The results are summarized and reported in table 14-20 as a National average for each highway system and for each of four intervals of increased axle-weight limits. The study was based entirely on increases in axle-weight limits and did not consider increases in motor vehicle width, length, and gross weight.

B. Concept and Approach to Solution

For any given increase in axle-weight limits, a reduction in ADT (when the same total tons of payload are hauled) will result in the same percentage reduction in truck transport costs and in E 18-kip axle applications to the highway. The E 18-kip highway construction-cost relationship is not a straight line function, and the net result of reducing ADT for a given increase in axle-weight limits is a percentage reduction in annual highway costs that is less than the percentage reduction in ADT and transport costs. Therefore, for any given increase in axle-weight limits, trial and error reductions of the ADT can be made to determine that marginal ADT which results in a benefit-cost ratio of 1.0.

An advantage in using the design concept of minimum pavement thickness (Method 1-M) for the marginal ADT analysis is that the increment of annual highway costs for a given increase in axle-weight limits will remain constant for any decrease in ADT volumes. Therefore, for a given increase in axle-weight limits, the percentage by which the incremental annual benefit has to be reduced to equal the incremental annual highway cost is equal to the reciprocal of the benefit-cost ratio. The ADT volume at the lower axle-weight level multiplied by this percentage gives the minimum economical ADT for the increase in axle-weight limits.

C. Results

Table 14-20 lists the marginal ADT's for the four intervals of change in axle-weight limit for the six highway systems and for the composite of the 10 census divisions (National average). The figures under the column headed Method 1-M are the marginal ADT's based on the minimum pavement design concept.

Table 14-21 shows the effect on the marginal ADT of variations in the minimum pavement design depth. For a given increase in axle-weight limits, the marginal ADT decreases as the minimum pavement depth increases. The marginal ADT's for the primary rural highway system were calculated on the basis of the minimum pavement design concept (Method 1-M), construction costs for the East North Central census division, and average ADT for the study period 1965 to 1985.

Table 14-20. -- Marginal ADT's based on Method 1-M, rigid pavements, and the concept of minimum pavement design depth - National average, or composite of 10 census divisions

Increase in single/tandem axle-weight limits, kips	Highway system		Method 1-M	Method 1
	No.	Name		
18/32 to 20/35	1	IR	914	1,082
	2	IU	1,390	1,631
	3	PR	147	397
	4	PU	299	443
	5	SR	31	142
	6	SU	874	1,090
20/35 to 22/38	1	IR	1,070	1,237
	2	IU	1,675	1,928
	3	PR	177	432
	4	PU	343	544
	5	SR	39	170
	6	SU	1,026	1,269
22/38 to 24/41	1	IR	1,307	1,478
	2	IU	2,058	2,322
	3	PR	217	488
	4	PU	468	708
	5	SR	53	209
	6	SU	1,255	1,528
24/41 to 26/44	1	IR	1,932	2,151
	2	IU	3,140	3,453
	3	PR	356	742
	4	PU	953	1,363
	5	SR	102	353
	6	SU	1,981	2,365

Table 14-21. --Marginal ADT's for various minimum pavement design depth based on Method 1-M, for the East North Central census division, rigid pavements, and the primary rural highway system, using the average ADT for the study period 1965 - 1985

Increase in single/tandem axle-weight limits, kips	Minimum pavement design depth, inches			
	7"	8"	9"	10"
18/32 to 20/35	413	245	156	107
20/35 to 22/38	434	256	183	129
22/38 to 24/41	449	290	224	162
24/41 to 26/44	696	459	357	256

CHAPTER 15

DISCUSSION, SUMMARY, AND CONCLUSIONS WITH RESPECT TO DIMENSION AND WEIGHT LIMITS

Chapters 10 through 14 report on the investigation of the economy of vehicle dimensions and weight with particular reference to axle-weight limits and overall combination length. It is desirable now to review these chapters in their overall concept, meaning, and significance of results.

1. LACK OF UNIFORMITY OF STATE LAWS

Difficulties for the trucking industry in interstate cartage are inherent in the State-to-State range of variation in the limiting legal vehicle dimensions of width, height, and length; in axle-weight limits from the low of 18,000 to 23,520 pounds for a single axle and from 32,000 to 44,000 pounds for a tandem axle; and in gross vehicle-weight limits. Furthermore, there is no sound engineering, economic, or industrial basis for the wide variation in legal limits of dimensions and weights. Economy of highway freight transportation could be significantly increased if uniformity of legal dimensions and weights could be achieved. This report on the desirable dimensions and weights of motor vehicles supplies a substantial foundation for use in establishing the desirable limits of vehicle dimensions and weights in each State.

2. TOLERANCES AND ENFORCEMENT

In several States, three factors exist having the same effects that would result from increasing axle-weight limits above the nominal, or basic, limits usually referred to. These factors are (a) the higher axle-weight or gross weight limits for local products of agriculture, forestry, or mining; (b) the enforcement tolerances (as high as 13 percent); and (c) overloading practice combined with weak enforcement efforts.

Relatively, certain States would not experience many additional E 18-kip axle applications to its pavements if the special limits for local products were made universal, and if the maximum axle-weight limits with tolerance were made the universal legal limits. These two changes combined with effective enforcement would provide for higher axle-weight limits to the benefit of transport without adding a significant increase in loading on the highways, certainly up to the 20,000/35,000-pound axle-weight limit.

3. BASIC FACTORS SUPPORTING THE RESEARCH

The economy of highway transportation as calculated includes in all cases the highway construction costs, maintenance costs of the highway, and the cost of operating trucks over the highways. In all calculations, the additional cost of highway construction for an increase in axle-weight limits was charged 100 percent against the benefit of decreased trucking cost within the 20-year analysis period, even though the additional cost of earth work, of the pavement base and surface, and of structures was for a type of work that could be expected to last for 50 to 75 years.

The analyses reported in Chapters 10 through 14 are believed to indicate the minimum economy to be expected. All factors on which the economy depended were conservatively determined.

4. THE GROSS VEHICLE-WEIGHT LIMITS

Specific attention is called to the inconsistency of the State and Federal limits on gross vehicle weight and the limits on axle weight, length of vehicles, and the number of axles. The purpose of the gross vehicle-weight law is particularly to protect bridges, and this purpose is not achieved in a State having a gross weight limit of 73,280 pounds and 18/32-kip axle-weight limits and permitting a conbination vehicle with double cargo units. With the 65-foot combination with double cargo units, economy depends upon hauling gross weights higher than 73,280 pounds or even 76,000 pounds, the limit common in the western States. Even if single axles were used exclusively, a reasonable gross limit for the 65-foot tractor with double trailers would be 82,000 pounds.

5. IMPLICATION OF HIGHER AXLE-WEIGHT LIMITS, GROSS WEIGHT LIMITS, AND VEHICLE LENGTHS

The highway systems existing today are composites of a wide range of structural capacities, considered from the viewpoint of their adaptation to truck axle-weight applications. It is not feasible to determine just what would happen to existing highway systems under legal provision for higher weight limits. It is logically concluded, however, that the economy indicated by the axle-weight limit study on one mile of new construction would apply equally well to existing highways.

As the pavements on existing highways reach a state of structural deterioration calling for reconstruction, it is presumed that the proper authorities would provide the desirable improvement. This action is in conformity with the practice over the last 40 years, which have experienced a continuous building and rebuilding of the roadways, including the replacement of structures. Over the last several years, the State laws have been modified from year to year to provide for higher limits of vehicle dimensions and weights. Therefore, if the States now having the lower dimension and weight limits desire to increase these limits to the levels existing in adjacent States, they would simply be repeating history and would continue to replace their highways as they have done in the past.

The economy of vehicle length is great and can be achieved without increasing highway costs, particularly with the use of the double 27-foot trailers drawn by a tractor under a limit of 65 feet.

6. HIGHER LIMITS FOR ACCESS-CONTROLLED HIGHWAYS

Although the 65-foot, or possibly the 70-foot, limit on vehicle length for combinations is desirable for use on all highway systems, it is reasonable to allow a greater length limit, and consequently a higher gross weight, on the Interstate highway sytem and on other routes with comparable standards of design. The experience on toll highways in Kansas, Indiana, Ohio, New York, and Massachusetts, where double 40-foot trailers are permitted to operate at an approximate length of 100 feet and gross vehicle weight of 125,000 pounds, has proved this operation to be successful. Toll authority reports indicate, on the whole, no interference with traffic, safe operation from the point of view of accidents, and high transport economy.

On these toll highways, no provision is made on the property of the toll authorities for making up and breaking down the double trailers at toll gates. If the 100-foot long double trailer were permitted on the entire Interstate system, public authorities or the private trucking industry would need to provide for a marshaling yard close to the Interstate interchange to avoid using the long combination on highways that are not divided or not fully access-controlled.

7. ECONOMY OF AXLE WEIGHT

The calculated economy of increasing axle-weight limits is high, particularly for the Interstate and primary highway systems under Method 1-M, in which minimum depths of pavement structure were used. It is established that overall highway transportation economy will prevail with increased axle-weight limits up to as high as 26/44 kips. The rate of return in proportion to the highway cost necessary to achieve these benefits is expressed in benefit-cost ratios on the order of 3 to 20.

8. SENSITIVITY OF FACTORS

In the analysis of the economy of axle-weight limits, the sensitivity of certain factors in controlling highway construction cost, the benefit-cost ratio, and E 18-kip axle applications was remarkably great. In the beginning no attempt was made to be precise or to develop smooth trends in the number of vehicles of each class at the different levels of axle-weight limit. Furthermore, the calculation of the E 18-kip axle applications was not controlled precisely. The earlier calculations using Method 1 indicated the sensitivity of these factors, but the cost was redone in some instances to provide for carrying the number of vehicles and E 18 factors to tenths. Also, preliminary checks were made to provide for a smooth transition of these factors from one level of axle-weight limit to the higher ones.

The pavement construction cost was found to be sensitive to the one-hundredth of an inch of pavement depth. That is, the final pavement construction cost would show an appreciable change in dollar value with the sensitivity of 0.01 inch of pavement and shoulder depth. For a mile of highway, this insignificant degree of depth is blown up considerably. Likewise, the number of vehicles was sensitive to both the E 18-kip application and the motor vehicle operating cost.

9. MARGINAL LIMITS OF WEIGHT AND ADT

Although some difficulties were experienced in developing procedures for determining the marginal limits of weight and ADT, results were obtained indicating that the single/tandem axle-weight limits beyond which no further increases in the economy of highway transportation can be expected were about 44/70 kips. The marginal gross weight limit is approximately 200,000 pounds per combination. In both cases, these marginal limits are so far beyond today's practical limits that there is little possibility that they would be seriously considered for new legislation. These marginal limits have value, however, because they show that any axle-weight limit in the neighborhood of 26/44 kips and any gross weight limit in the area of 125,000 pounds (the present limit on toll highways where the double 40-foot cargo units are permitted) should achieve the economy that this study indicates is attainable.

The study to determine the average daily traffic volume below which the increase in axle-weight limit would not produce a gain in economy indicated that ADT's as low as 500 will result in economy at higher axle-weight limits. On 2-lane, bidirectional secondary highways, an increase to 26/44-kip limits would give a benefit-cost ratio of 1.0 at an ADT of about 500 vehicles of all classes. For the primary rural highway system, a 4-lane divided highway with an ADT of 2,000 would produce a benefit-cost ratio of 1.0 for the 26/44-kip limits.

10. MINIMUM PAVEMENT DEPTH AND MARGINAL LIMITS

Method 1-M for determining axle-weight economy was developed to correct for the fact that the AASHO interim pavement design guides used in this study often resulted in a depth of pavement structure less than that currently considered adequate by the highway departments. Because the AASHO design formula produced design depths at the higher axle-weight limits that were still materially below today's State minimum depths, in applying Method 1-M an increment of pavement depth was added to the minimum depth for each increase in axle-weight limit.

The marginal ADT--that ADT at which the benefit-cost ratio would be 1.0--could not be calculated on a normal basis, because the marginal ADT is so low that the pavement design depth resulting from the design formula is far below the minimum design depth considered to be practical. The scheme used in Chapter 14, however, results in a reasonable approximation of the marginal ADT.

In theory, as the ADT decreases, the pavement design depth, pavement costs, and the total dollar volume of transport benefits decrease, all in some ratio to each other that is not a constant. Therefore, it can be expected that the marginal ADT is a low traffic volume. In the opposite direction, the marginal axle-weight limits are high (46/70 kips), because the pavement design depth increases more slowly as the ADT (E 18-kip axle applications) increases, while at the same time the pavement cost decrease in dollars per cubic yard in place.

11. RAMP WIDTH FOR 102-INCH VEHICLE WIDTH LIMIT

The estimated highway construction cost to match increased axle-weight limits would not require any increase in the cost of interchange ramps and other comparatively narrow facilities. For a change in vehicle length, however, the off-tracking may necessitate wider paved lanes on some interchange ramps or on sharp corners in some urban areas. The analyses using Method 4 make no allowance for this possible increase in highway cost, but it is recognized that such increases might come about. The cost increase, however, would be relatively small.

Because of the difficulty of getting a reliable measurement, the economy of vehicle width has not been developed in detail. Chapter 13, in which the study by the A. T. Kearney Company is discussed, gives some indication that there is modest economy in the change to 102 inches of vehicle width. This economy is not priced out on the basis of increased highway cost for increased vehicle width, because the general geometrics of design are now adequate to provide the necessary safety for the 102-inch width.

Where existing traffic lanes are less than 12 feet, reconstruction will normally be to widen enough lanes to accomodate the 102-inch width, even though the 96-inch width may likely continue to be the legal maximum. It should be recognized that ramp design and construction for the 102-inch wide vehicle may require wider pavement than would the 96-inch limit. Again, no estimate of this cost has been made because it would be relatively small.

12. TRUCK ADT

In all of the analyses for the economy of increased vehicle weight and length, there is an indicated reduction in the average daily traffic of trucks from the 2D (2-axle, 6-tired, single unit) upward. In actual practice, it is probable that this decrease in daily truck traffic will not actually materialize. Two factors may prevent it from taking place. The normal growth in truck use to serve the needs of growing industry and increasing population would normally prevent any decrease in truck ADT. Second, if trucking becomes more profitable with increased limits of vehicle dimensions and weight, such increased profitability is apt to induce greater use of the highway by heavy trucking.

13. PROBABLE ACTUAL USE OF HIGHER LIMITS

In the analyses of axle-weight economy and of the economy of combination length, it is assumed that the same number of tons of payload would be hauled at the increased levels of axle-weight limit and length as would be hauled at the existing limits. This assumption is one not likely to be realized for a reason already discussed: any liberalizing of vehicle limits on dimensions and weights probably will result in increased use of the highways by heavier trucks. However, in order to determine the relative effects of increases in limit, it was essential to hold constant all factors except the change in the limit of weight or dimension.

As the States approach uniformity in limits, a change made by any single State will affect trucking practice in adjacent States. If a State has low legal limits, trucks operating between that State and surrounding States having higher limits will not be able to take full advantage of those higher limits. The maximum weight or maximum dimensions used by truckers in interstate travel is controlled by the State having the minimum limit. The analyses for economy of vehicle weight and of vehicle length do not take into consideration these probable changes in trucking practice.

14. FEASIBILITY OF DOUBLE- AND TRIPLE-CARGO COMBINATIONS

A combination made up of a tractor, a semitrailer, and a full trailer with the conventional type of axle arrangements could have a total of nine axles: the front (or steering) axle and four sets of tandem axles. This type of axle arrangement is common on the toll highways permitting the 100-foot long combination with 40-foot double trailers. A question arises whether, considering the mechanical and operational features of the vehicle, the 9-axle combination using 27-foot trailers for a total length of 65 feet is practical. The trucking industry may know the answer, but this report merely raises the question.

The combination of tractor and three 27-foot long trailers in an overall length of 100 feet is a practical one that has proved satisfactory in test runs in Idaho and Nevada. The triple-trailer combination should, however, be restricted to divided highways with full control of access.

15. EFFECT ON PASSENGER CARS

Increased vehicle weights and lengths may affect passenger car traffic as much favorably as unfavorably. On the favorable side, the passenger car will be required to pass fewer and slower-moving trucks, because of the fewer trips required to transport a given tonnage of cargo. This is particularly true for an increase in axle-weight limits, but it is equally true for double-cargo combinations that could theoretically reduce by half the number of combination vehicles. The net result of using the double-trailer as opposed to the single-trailer combination is, therefore, a reduced total length of all trucks to be passed by passenger cars, although individual truck length to be passed might be 65 feet instead of 50 feet.

A greater number of trucks having heavy gross weights might have to be passed on plus grades, provided that the weight-horsepower ratio does not increase. The present trend is toward lower weight-horsepower ratios in vehicles operating on the highway and those being manufactured.

16. THE BENEFICIARIES OF HIGHER LIMITS ON VEHICLE DIMENSION AND WEIGHT

It is easy to conclude that increased vehicle dimension and axle-weight limits would result in benefits to the owners and operators of the vehicles taking advantage of the more liberal limits. In the end, however, it may be assumed that at least a fair share of these benefits would be passed on to the public at large. About 25 percent of the haulage of freight on the public highway is done by common carriers whose tariff schedules are regulated by State regulatory commissions and the Interstate Commerce Commission. If higher dimension and weight limits permitted these carriers to earn substantially more profit, the regulatory commission would reduce the tariff schedules. Again, in private industry, where haulage is done by private operators carrying their own goods, general competition would control wholesale and retail prices to some extent. There is no reason to expect the competitive economic laws to operate differently in the transportation industry than they do in the manufacturing and distribution industries.

Consistent with general public policy, cost responsibility of the users of the highway should be assigned on some equitable basis related to cost incurred and benefits received. There is so great a margin of benefits over costs that any properly allocated additional tax burden on the heavier trucks that would utilize higher axle-weight limits would still leave then with substantial net benefits.

17. SHORTENING OF SERVICE LIFE OF PAVEMENTS, RESULTING FROM INCREASED AXLE-WEIGHT LIMITS

The shortening of the years of service life resulting from increased axle-weight limits was not used in any of the analysis methods adopted for this study. Instead, the effect of any increase in E 18-kip axle application was taken care of by increasing the pavement depth. Of interest, however, is table 15-2, giving the reductions in service life for Method 1-M from the design life of 20 years. The reduced service life calculated is the elapsed time in years that it would take for the pavements to have received the total number of E 18-kip applications that would be received in 20 years under a lower axle-weight limit.

Table 15-2. -- Shortened years of average service life with increase in axle-weight limits for Method 1-M with transition

Highway system and pavement type	Single/tandem axle-weight limits, kips					Single/tandem axle-weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	22/44
	East North Central					West South Central				
1. Interstate rural										
Rigid	20.0	17.4	15.3	13.6	12.2	20.0	16.4	13.8	11.9	10.5
Flexible	20.0	15.7	12.8	10.7	9.2	20.0	16.2	12.6	11.6	10.2
2. Interstate urban										
Rigid	20.0	18.4	17.1	15.8	14.8	20.0	18.1	16.4	15.1	13.9
Flexible	20.0	18.3	16.9	15.6	14.5	20.0	18.9	17.9	16.9	16.0
3. Primary rural										
Rigid	20.0	19.5	19.0	18.5	18.1	20.0	19.2	18.4	17.7	17.1
Flexible	20.0	17.4	15.3	13.5	12.1	20.0	17.6	15.7	14.0	12.7
4. Primary urban										
Rigid	20.0	19.4	18.9	18.4	18.0	20.0	19.0	18.2	17.4	16.6
Flexible	20.0	17.1	15.0	13.2	11.9	20.0	17.4	15.4	13.8	12.6
5. Secondary rural										
Rigid	20.0	19.8	19.6	19.3	19.1	20.0	19.8	19.6	19.3	19.1
Flexible	20.0	19.4	18.8	18.2	17.6	20.0	19.4	18.8	18.2	17.6
6. Secondary urban										
Rigid	20.0	19.6	19.3	18.9	18.5	20.0	19.6	19.3	18.9	18.5
Flexible	20.0	19.1	18.1	17.0	16.0	20.0	19.0	18.0	17.1	16.2
	Mountain					Pacific				
1. Interstate rural										
Rigid	20.0	18.4	16.9	15.6	14.4	20.0	16.8	14.4	12.5	11.0
Flexible	20.0	19.6	19.2	18.8	18.3	20.0	16.7	14.3	12.5	11.1
2. Interstate urban										
Rigid	20.0	17.5	15.5	13.9	12.6	20.0	17.9	16.1	14.5	13.3
Flexible	20.0	19.2	18.5	17.8	17.1	20.0	18.6	17.4	16.3	15.4
3. Primary rural										
Rigid	20.0	19.5	19.0	18.5	18.0	20.0	19.1	18.2	17.4	16.8
Flexible	20.0	19.8	19.7	19.5	19.2	20.0	18.2	16.6	15.3	14.2
4. Primary urban										
Rigid	20.0	17.7	15.8	14.3	13.1	20.0	18.2	16.7	15.4	14.3
Flexible	20.0	19.2	18.4	17.7	17.1	20.0	17.7	15.9	14.5	13.4
5. Secondary rural										
Rigid	20.0	19.8	19.7	19.5	19.4	20.0	19.8	19.6	19.5	19.3
Flexible	20.0	19.9	19.8	19.6	19.5	20.0	19.6	19.2	18.8	18.4
6. Secondary urban										
Rigid	20.0	19.3	18.6	18.0	17.4	20.0	19.0	18.1	17.2	16.5
Flexible	20.0	19.4	18.9	18.3	17.9	20.0	17.5	15.6	14.1	12.9

18. NATIONAL SUMMARY OF METHOD 1-M

On the bottom lines of table 15-3 are the benefit-cost ratios for Method 1-M for each of the six highway systems. The National average ratios in this table offer a better indication of the overall economy of the increased axle-weight limits than is obtainable separately for each of the 10 census divisions. As may be expected, the secondary urban system has the lowest benefit-cost ratios ranging from 2.1 to 5.6. The high ratios--up to 55.7 on the primary urban system--again indicate that the trucking cost reductions are many times the highway cost increase for the full range of axle-weight increases up to 26/44 kips.

19. ANNUAL REDUCTIONS IN TRUCK OPERATING COSTS BY HIGHWAY SYSTEMS

The analyses for economy of axle-weight limit by Methods 1, 2, 3, 4, and 6 were made on the basis of one highway mile of new construction. It is of considerable importance to explore the truck operating costs on an annual basis for the entire highway system mileage. In tables 15-4 and 15-5 for Method 1-M and tables 15-6 and 15-7 for Method 4 are found the system mileages, truck-miles, and truck operating costs for the ADT's of 1965 and 1984. Tables 15-4 and 15-6 give daily values for the basic information. Tables 15-5 and 15-7 give the base totals for each of the two years for length step 0 and the yearly differences from this base to the higher axle-weight limits on the right of the base entries.

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Table 15-3.- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984-- National average

Highway System 1. IR   Method of Analysis 1-M with transition   Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	222,016	223,394	225,251	227,574	229,608	186,899	188,717	190,972	193,590	195,893
b. Bridge structures	200,634	202,212	204,347	207,648	210,948	200,634	202,212	204,347	207,648	210,948
c. Earthwork and drainage	190,465	190,505	190,561	190,641	190,709	190,465	190,591	190,757	190,977	191,173
d. Total construction cost	613,115	616,111	620,159	625,863	631,265	577,998	581,520	586,076	592,215	598,014
2. Equivalent uniform annual capital cost *	53,454	53,716	54,069	54,566	55,037	50,393	50,700	51,096	51,632	52,138
3. Incremental annual cost										
a. Capital cost	–	262	353	497	471	–	307	396	536	506
b. Maintenance cost of pavement and shoulders	–	7	9	11	10	–	6	8	9	8
c. Maintenance cost of structures	–	12	18	25	25	–	12	18	25	25
d. Total equivalent uniform annual highway cost	–	281	380	533	506	–	325	422	570	539
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	232,044	228,713	224,003	218,657	215,181	232,044	228,713	224,003	218,657	215,181
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	3,331	4,710	5,346	3,476	–	3,331	4,710	5,346	3,476
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	11.9	12.4	10.0	6.9	–	10.2	11.2	9.4	6.4

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 15-3.- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 2. IU   Method of Analysis 1-M with transition   Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	222,792	223,852	225,279	227,088	228,761	196,957	197,728	198,779	200,113	201,361
b. Bridge structures	1,294,314	1,296,265	1,299,229	1,303,246	1,307,264	1,294,314	1,296,265	1,299,229	1,303,246	1,307,264
c. Earthwork and drainage	492,872	492,902	492,944	493,006	493,063	492,871	492,928	493,008	493,122	493,229
d. Total construction cost	2,009,978	2,013,019	2,017,452	2,023,340	2,029,088	1,984,142	1,986,921	1,991,016	1,996,481	2,001,854
2. Equivalent uniform annual capital cost *	175,240	175,505	175,892	176,405	176,906	172,987	173,230	173,587	174,063	174,532
3. Incremental annual cost - a. Capital cost	–	265	387	513	501	–	243	357	476	469
b. Maintenance cost of pavement and shoulders	–	9	11	13	12	–	4	5	7	6
c. Maintenance cost of structures	–	111	139	193	193	–	111	139	193	193
d. Total equivalent uniform annual highway cost	–	385	537	719	706	–	358	501	676	668
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits: a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	368,086	357,380	346,460	332,350	323,250	368,086	357,380	346,460	332,350	323,250
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	10,706	10,920	14,110	9,100	–	10,706	10,920	14,110	9,100
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	27.8	20.3	19.6	12.9	–	29.9	21.8	20.9	13.6

* Calculated at 6 percent interest rate per annum and 20 years.

Table 15-3.—Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 3. PR — Method of Analysis 1-M with transition — Census Division All

Cost item	Rigid Pavement					Flexible Pavement				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	180,568	180,808	181,212	181,775	182,301	143,781	144,424	145,456	146,656	147,757
b. Bridge structures	31,194	31,439	31,816	32,308	32,801	31,194	31,438	31,816	32,308	32,801
c. Earthwork and drainage	86,710	86,717	86,730	86,751	86,769	86,710	86,755	86,831	86,929	87,020
d. Total construction cost	298,472	298,964	299,758	300,834	301,871	261,685	262,617	264,103	265,893	267,578
2. Equivalent uniform annual capital cost *	26,022	26,065	26,134	26,228	26,319	22,815	22,896	23,026	23,182	23,329
3. Incremental annual cost										
a. Capital cost	—	43	69	94	91	—	81	130	156	147
b. Maintenance cost of pavement and shoulders	—	1	1	2	2	—	2	3	3	3
c. Maintenance cost of structures	—	2	3	4	4	—	2	3	4	4
d. Total equivalent uniform annual highway cost	—	46	73	100	97	—	85	136	163	154
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	56,018	54,860	53,425	51,892	50,992	56,018	54,860	53,425	51,892	50,992
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	1,158	1,435	1,533	900	—	1,158	1,435	1,533	900
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	25.2	19.7	15.3	9.3	—	13.6	10.6	9.4	5.8

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 15-3.-Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984--National average

Highway System 4. PU — Method of Analysis 1-M with transition — Census Division All

Cost item	Rigid Pavement					Flexible Pavement				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	180,567	181,015	181,634	182,420	183,153	145,413	146,239	147,335	148,553	149,645
b. Bridge structures	119,813	120,547	121,597	122,970	124,344	119,813	120,547	121,597	122,970	124,344
c. Earthwork and drainage	173,963	173,978	173,999	174,027	174,054	173,963	174,025	174,106	174,204	174,297
d. Total construction cost	474,343	475,540	477,230	479,417	481,551	439,189	440,811	443,038	445,727	448,286
2. Equivalent uniform annual capital cost *	41,356	41,460	41,607	41,798	41,984	38,291	38,432	38,626	38,861	39,083
3. Incremental annual cost										
a. Capital cost	—	104	147	191	186	—	141	194	235	222
b. Maintenance cost of pavement and shoulders	—	3	4	5	4	—	5	5	5	5
c. Maintenance cost of structures	—	7	9	12	12	—	7	9	12	12
d. Total equivalent uniform annual highway cost	—	114	160	208	202	—	153	208	252	239
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	134,610	128,190	121,647	115,221	112,063	134,610	128,190	121,647	115,221	112,063
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	6,420	6,543	6,426	3,158	—	6,420	6,543	6,426	3,158
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	56.3	40.9	30.9	15.6	—	42.0	31.5	25.5	13.2

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 15-3.-Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 5. SR   Method of Analysis 1-M with transition   Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	104,044	104,095	104,157	104,241	104,324	82,197	82,290	82,416	82,571	82,730
b. Bridge structures	9,244	9,329	9,439	9,568	9,698	9,244	9,328	9,439	9,568	9,698
c. Earthwork and drainage	34,249	34,251	34,253	34,255	34,258	34,250	34,255	34,266	34,278	34,290
d. Total construction cost	147,537	147,675	147,849	148,064	148,280	125,691	125,873	126,121	126,417	126,718
2. Equivalent uniform annual capital cost *	12,863	12,875	12,890	12,909	12,928	10,958	10,974	10,996	11,022	11,048
3. Incremental annual cost										
a. Capital cost	—	12	15	19	19	—	16	22	26	26
b. Maintenance cost of pavement and shoulders	—	0	0	0	0	—	0	0	0	0
c. Maintenance cost of structures	—	1	1	1	1	—	1	1	1	1
d. Total equivalent uniform annual highway cost	—	13	16	20	20	—	17	23	27	27
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	10,068	9,777	9,451	9,048	8,816	10,068	9,777	9,451	9,048	8,816
5. Incremental equivalent uniform decrements in annual vehicle operating cost	—	291	326	403	232	—	291	326	403	232
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	—	22.4	20.4	20.2	11.6	—	17.1	14.2	14.9	8.6

* Calculated at 6 percent interest rate per annum and 20 years.

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Table 15-3.- Comparison of highway cost and motor vehicle operating cost for five levels of axle-weight maximum limits, for the 20-year period 1965 through 1984 -- National average

Highway System 6. SU   Method of Analysis 1-M with transition   Census Division All

Cost item	Rigid Pavement: Single/tandem axle weight maximum limits, kips					Flexible Pavement: Single/tandem axle maximum weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
COST OF PROVIDING HIGHWAY FACILITIES										
1. Construction cost per mile:										
a. Pavement and shoulders	104,044	104,164	104,338	104,548	104,752	82,197	82,427	82,784	83,185	83,571
b. Bridge structures	40,814	42,826	45,352	48,346	51,341	40,814	42,826	45,352	48,346	51,341
c. Earthwork and drainage	49,078	49,082	49,087	49,095	49,102	49,078	49,096	49,125	49,159	49,191
d. Total construction cost	193,936	196,072	198,777	201,989	205,195	172,089	174,349	177,261	180,690	184,103
2. Equivalent uniform annual capital cost *	16,908	17,095	17,330	17,610	17,890	15,004	15,201	15,454	15,753	16,050
3. Incremental annual cost										
a. Capital cost	–	187	235	280	280	–	197	253	299	297
b. Maintenance cost of pavement and shoulders	–	0	1	1	1	–	1	1	1	1
c. Maintenance cost of structures	–	17	21	25	25	–	17	21	25	25
d. Total equivalent uniform annual highway cost	–	204	257	306	306	–	215	275	325	323
MOTOR TRUCK OPERATING COST										
4. Annual operating cost of vehicles affected by axle weight limits:										
a. For 1965 ADT										
b. Total equivalent uniform annual operating cost *	29,091	28,301	27,344	26,202	25,521	29,091	28,301	27,344	26,202	25,521
5. Incremental equivalent uniform decrements in annual vehicle operating cost	–	790	957	1,142	681	–	790	957	1,142	681
RATIO OF ANNUAL DECREASE IN MOTOR TRUCK OPERATING COST TO ANNUAL HIGHWAY COST										
6. Ratio of incremental reduction in truck operating cost to incremental increase in equivalent annual highway cost	–	3.9	3.7	3.7	2.2	–	3.7	3.5	3.5	2.1

* Calculated at 6 percent interest rate per annum and 20 years.

An examination of tables 15-5 (axle weight, Method 1-M) and 15-7 (length steps, Method 4) discloses phenomenal annual reductions in truck operating costs. A change from the 18/32-kip limits to 20/35 kips would have resulted in reductions for 1965 from $25.2 million on the Interstate urban system to $249.7 million on the primary rural system. For all six systems, the combined reductions are $623.9 million. For 1965 and the 26/44-kip limits, the combined six-system reductions are $2,703.9 million. For 1984 the truck operating-cost reductions range up to four times those of 1965. The differences between 1965 and 1984 result from the forecast of truck ADT and traffic composition.

Comparing tables 15-5 and 15-7 shows that from length step 0 to step 1 the change to the 65-foot maximum length of vehicle combination reduces the truck operating cost two to three times as much as does the change in axle-weight limit from 18/32 to 20/35 kips. This length change from step 0 to step 1 for 1965 results in cost reductions of $43.4 million (secondary urban system) to $741.7 million (primary rural system) and $1,227.8 million (all systems). These cost reductions are for the single years 1965 and 1984. For the entire period from 1965 to 1984, they would be approximately 20 times the average for the two years.

Table 15-4.-- Centerline miles, truck ADT, daily truck-miles, and daily operating costs, by axle-weight limits and highway system: 1965 and 1984--Method 1-M, National total

Highway system	Item	18/32-kip axle-weight limits		20/35-kip axle-weight limits		22/38-kip axle-weight limits		24/41-kip axle-weight limits		26/44-kip axle-weight limits	
		1965	1984	1965	1984	1965	1984	1965	1984	1965	1984
1. IR	Centerline miles	15,648	34,880	15,648	34,880	15,648	34,880	15,648	34,880	15,648	34,880
	Truck ADT (National wtd. average)	1,091	2,047	1,049	1,974	1,002	1,888	953	1,796	908	1,713
	Truck-miles, daily (1,000)	17,065	71,383	16,415	68,862	15,673	65,862	14,905	62,653	14,206	59,744
	Truck (vehicle) operating costs, daily ($1,000)	6,592	27,947	6,458	27,476	6,302	26,891	6,142	26,266	6,001	25,731
2. IU	Centerline miles	3,213	6,002	3,213	6,002	3,213	6,002	3,213	6,002	3,213	6,002
	Truck ADT (National wtd. average)	1,882	4,172	1,800	4,004	1,712	3,821	1,598	3,570	1,499	3,355
	Truck-miles, daily (1,000)	6,047	25,042	5,782	24,031	5,501	22,932	5,133	21,429	4,817	20,137
	Truck (vehicle) operating costs, daily ($1,000)	2,223	9,297	2,154	9,046	2,081	8,774	1,981	8,379	1,898	8,051
3. PR	Centerline miles	184,861	197,874	184,861	197,874	184,861	197,874	184,861	197,874	184,861	197,874
	Truck ADT (National wtd. average)	333	388	319	372	303	353	286	333	271	316
	Truck-miles, daily (1,000)	61,559	75,786	58,952	73,549	55,998	69,873	52,826	65,970	50,020	62,528
	Truck (vehicle) operating costs, daily ($1,000)	23,290	29,441	22,606	28,620	21,845	27,708	21,050	26,774	20,373	25,992
4. PU	Centerline miles	19,108	29,455	19,108	29,455	19,108	29,455	19,108	29,455	19,108	29,455
	Truck ADT (National wtd. average)	831	1,096	784	1,034	736	966	676	887	628	825
	Truck-miles, daily (1,000)	15,876	32,287	14,982	30,449	14,060	28,444	12,909	26,131	11,999	24,309
	Truck (vehicle) operating costs, daily ($1,000)	5,824	11,957	5,546	11,386	5,262	10,772	4,914	10,078	4,650	9,557
5. SR	Centerline miles	602,899	665,332	602,899	665,332	602,899	665,332	602,899	665,332	602,899	665,332
	Truck ADT (National wtd. average)	61	82	58	78	55	73	51	68	48	64
	Truck-miles, daily (1,000)	36,904	54,404	35,079	51,631	32,947	48,405	30,787	45,279	28,922	42,561
	Truck (vehicle) operating costs, daily ($1,000)	13,467	20,127	12,955	19,394	12,365	18,512	11,773	17,686	11,267	16,991
6. SU	Centerline miles	18,639	28,104	18,639	28,104	18,639	28,104	18,639	28,104	18,639	28,104
	Truck ADT (National wtd. average)	194	223	188	215	179	204	166	190	155	178
	Truck-miles, daily (1,000)	3,619	6,277	3,497	6,050	3,336	5,742	3,102	5,349	2,897	5,007
	Truck (vehicle) operating costs, daily ($1,000)	1,316	2,299	1,284	2,239	1,239	2,154	1,173	2,046	1,115	1,952
All systems (1-6)	Centerline miles	844,368	961,647	844,368	961,647	844,368	961,647	844,368	961,647	844,368	961,647
	Truck ADT (National wtd. average)	167	277	160	265	151	251	142	236	134	223
	Truck-miles, daily (1,000)	141,070	266,179	134,707	254,572	127,515	241,258	119,662	226,811	112,861	214,286
	Truck (vehicle) operating costs, daily ($1,000)	52,712	101,068	51,003	98,161	49,094	94,811	47,033	91,229	45,304	88,274

Table 15-5.--Annual average truck traffic, annual truck-miles, and annual truck operating costs at base axle-weight limits and differences between the base and higher axle-weight limits: 1965 and 1984--Method 1-M, National total

Highway system	Item	18/32-kip axle-weight limits		20/35-kip axle-weight limits		22/38-kip axle-weight limits		24/41-kip axle-weight limits		26/44-kip axle-weight limits	
		1965 base	1984 base	1965	1984	1965	1984	1965	1984	1965	1984
1. IR	Truck average annual traffic	398,215	747,155	15,330	26,645	32,485	58,035	50,370	91,615	66,795	121,910
	Truck-miles, annual (millions)	6,228.7	26,054.8	237.3	920.2	508.1	2,015.2	788.4	3,186.5	1,043.5	4,248.2
	Truck (vehicle) operating cost, annual (million dollars)	2,406.1	10,200.7	48.9	171.9	105.9	385.4	164.3	613.6	215.7	808.8
2. IU	Truck average annual traffic	686,930	1,522,780	29,930	61,320	62,050	128,115	103,660	219,730	139,795	298,205
	Truck-miles, annual (millions)	2,207.2	9,140.3	96.7	369.0	199.3	770.2	333.6	1,318.7	449.0	1,790.3
	Truck (vehicle) operating cost, annual (million dollars)	811.4	3,393 4	25.2	91.6	51.8	190.9	88.3	335.1	118.6	454.8
3. PR	Truck average annual traffic	121,545	141,620	5,110	5,840	10,950	12,775	17,155	20,075	22,630	26,280
	Truck-miles, annual (millions)	22,469.0	28.026.9	951.6	1,181.5	2,029.8	2,523.2	3,187.5	3,947.8	4,211.7	5,204.2
	Truck (vehicle) operating cost, annual (million dollars)	8,500.9	10,746.0	249.7	299.7	527.4	632.5	817.6	973.5	1,064.7	1,258.9
4. PU	Truck average annual traffic	303,315	400,040	17,155	22,630	34,675	47,450	56,575	76,285	74,095	98,915
	Truck-miles, annual (millions)	5,794.7	11,784.8	326.3	670.9	662.8	1,402.7	1,083.0	2,246.9	1,415.1	2,912.0
	Truck (vehicle) operating cost, annual (million dollars)	2,125.8	4,364.3	101.5	208.4	205.1	432.5	332.2	685.8	428.5	876.0
5. SR	Truck average annual traffic	22,265	29,930	1,095	1,460	2,190	3,285	3,650	5,110	4,745	6,570
	Truck-miles, annual (millions)	13,470.0	19,857.5	666.1	1,012.1	1,444.3	2,189.6	2,232.7	3,330.6	2,913.4	4,322.7
	Truck (vehicle) operating cost, annual (million dollars)	4,915.5	7,346.4	186.9	267.5	402.2	598.5	618.3	891.0	803.0	1,144.6
6. SU	Truck average annual traffic	70,810	81,395	2,190	2,920	5,475	6,935	10,220	12,045	14,235	16,425
	Truck-miles, annual (millions)	1,320.9	2,291.1	44.5	82.9	103.3	195.3	188.7	338.7	263.5	463.6
	Truck (vehicle) operating cost, annual (million dollars)	480.3	839.1	11.7	21.9	28.1	52.9	52.2	92.3	73.4	126.7
All systems (1-6)	Truck average annual traffic	60,955	101,105	2,555	4,380	5,840	9,490	9,125	14,965	12,045	19,710
	Truck-miles, annual (millions)	51,490.5	97,155.4	2,322.5	4,236.6	4,947.6	9,096.2	7,813.9	14,369.2	10,296.2	18,941.0
	Truck (vehicle) operating cost, annual (million dollars)	19,240.0	36,889.9	623.9	1,061.0	1,320.5	2.283.7	2.072.9	3.591.3	2.703.9	4.669.8

Table 15-6.-- Centerline miles, truck ADT, daily truck-miles, and daily truck operating costs, by vehicle length steps and highway system: 1965 and 1984--Method 4, National totals

Highway system	Item	Step 0		Length step 1		Length step 2		Length step 3		Length step 4	
		1962 axle-weight limit		35/50/55/65 feet		35/55/60/65 feet		40/55/65/65 feet		40/55/70/70 feet	
		1965	1984	1965	1984	1965	1984	1965	1984	1965	1984
1. IR	Centerline miles, December 31, 1965	15,648	34,880	15,648	34,880	15,648	34,880	15,648	34,880	15,648	34,880
	Truck ADT (National wtd. average)	1,091	2,047	931	1,761	889	1,677	834	1,580	809	1,529
	Truck-miles, daily (1,000)	17,065	71,383	14,567	61,411	13,910	58,507	13,057	55,105	12,660	53,348
	Truck (vehicle) operating costs, daily ($1,000)	6,592	27,947	6,007	25,867	5,742	24,707	5,437	23,494	5,277	22,794
2. IU	Centerline miles, December 31, 1965	3,213	6,002	3,213	6,002	3,213	6,002	3,213	6,002	3,213	6,002
	Truck ADT (National wtd. average)	1,882	4,172	1,677	3,727	1,639	3,634	1,479	3,291	1,458	3,239
	Truck-miles, daily (1,000)	6,047	25,042	5,388	22,372	5,265	21,814	4,753	19,750	4,685	19,441
	Truck (vehicle) operating costs, daily ($1,000)	2,223	9,297	2,027	8,550	1,978	8,326	1,799	7,004	1,772	7,484
3. PR	Centerline miles, December 31, 1965	184,861	197,874	184,861	197,874	184,861	197,874	184,861	197,874	184,861	197,874
	Truck ADT (National wtd. average)	333	388	291	345	280	330	260	307	255	301
	Truck-miles, daily (1,000)	61,559	76,786	53,881	68,200	51,843	65,293	48,097	60,565	47,144	59,563
	Truck (vehicle) operating costs, daily ($1,000)	23,290	29,441	21,258	27,415	20,448	26,267	19,129	24 712	18,748	24,203
4. PU	Centerline miles, December 31, 1965	19,108	29,455	19,108	29,455	19,108	29,455	19,108	29,455	19,108	29,455
	Truck ADT (National wtd. average)	831	1,096	708	933	694	912	[illegible]	823	617	812
	Truck-miles, daily (1,000)	15,876	32,287	13,535	27,472	13,268	26,867	11,928	24,230	11,785	23,906
	Truck (vehicle) operating costs, daily ($1,000)	5,824	11,957	5,053	10,399	4,946	10,157	4,477	9,236	4,420	9,109
5. SR	Centerline miles, December 31, 1965	602,899	665,332	602,899	665,332	602,899	665,332	602,899	665,332	602,899	665,332
	Truck ADT (National wtd. average)	61	82	62	86	60	83	55	76	54	75
	Truck-miles, daily (1,000)	36,904	54,404	37,294	56,982	36,415	55,350	33,173	50,643	32,855	50,039
	Truck (vehicle) operating costs, daily ($1,000)	13,467	20,127	13,806	21,404	13,454	20,769	12,342	19,140	12,211	18,903
6. SU	Centerline miles, December 31, 1965	18,639	28,104	18,639	28,104	18,639	28,104	18,639	28,104	18,639	28,104
	Truck ADT (National wtd. average)	194	223	174	202	171	198	153	178	152	176
	Truck-miles, daily (1,000)	3,619	6,277	3,239	5,672	3,179	5,557	2,856	5,005	2,828	4,950
	Truck (vehicle) operating costs, daily ($1,000)	1,316	2,299	1,197	2,118	1,174	2,072	1,061	1,879	1,049	1,858
All systems (1-6)	Centerline miles, December 31, 1965	844,368	961,647	844,368	961,647	844,368	961,647	844,368	961,647	844,368	961,647
	Truck ADT (National wtd. average)	167	277	151	252	147	243	135	224	133	220
	Truck-miles, daily (1,000)	141,070	266,179	127,904	242,109	123,880	233,388	113,864	215,598	111,957	211,247
	Truck (vehicle) operating costs, daily ($1,000)	52,712	101,068	49,348	95,753	47,752	92,298	44,245	86,065	43,477	84,351

Table 15-7.-- Annual average truck traffic, annual truck-miles, and annual truck operating costs at length step 0 and differences between the base step 0 and steps 1, 2, 3, and 4: Method 4, National totals

Note: All differences are decreases from the base except as noted by plus (+) sign.

Highway system	Item	Step 0		Length step 1		Length step 2		Length step 3		Length step 4	
		1962 axle-weight limit		35/50/55/65 feet		35/55/60/65 feet		40/55/65/65 feet		40/55/70/70 feet	
		1965 base	1984 base	1965	1984	1965	1984	1965	1984	1965	1984
1. IR	Truck annual average traffic	398,215	747,155	58,400	104,390	73,730	135,050	93,805	[illegible]	102,[illegible]	189,070
	Truck-miles, annual (millions)	6.228.7	26,054.8	911.8	3,639.8	1,151.6	4,699.7	1,462.[illegible]	[illegible]5	1,[illegible].8	6,582.8
	Truck (vehicle) operating cost, annual (million dollars)	2,406.1	10,200.7	213.5	759.2	310.3	1,182.6	421.[illegible]	1,625.[illegible]	440.0	1.880.[illegible]
2. IU	Truck annual average traffic	686,930	1,522,780	74,825	162,425	88,695	196,370	147,095	[illegible]	[illegible]	340,549
	Truck-miles, annual (millions)	2,207.2	9,140.3	240.5	974.6	285.4	1,178.2	472.3	[illegible].6	[illegible].1	2,044.[illegible]
	Truck (vehicle) operating cost, annual (million dollars)	811.4	3,393.4	71.5	272.7	89.4	354.4	[illegible]	[illegible].9	[illegible]	[illegible].7
3. PR	Truck annual average traffic	121,545	141,620	15,330	15,695	19,345	21,170	[illegible],645	[illegible]	28,470	31,755
	Truck-miles, annual (millions)	22,469.0	26,026.9	2,802.5	3,133.9	3,546.3	4,194.9	4,91[illegible]	[illegible].2	5,261.5	6,266.4
	Truck (vehicle) operating cost, annual (million dollars)	8,500.9	10,746.0	741.7	739.5	1,037.3	1,15[illegible].5	1,51[illegible]	[illegible]1	1,657.8	1,911.9
4. PU	Truck average annual traffic	303,315	400,040	44,895	59,495	50,005	67,[illegible]60	75,[illegible]	[illegible],645	78,110	103,660
	Truck-miles annual (millions)	5,794.7	11,784.8	854.5	1,757.5	951.9	1,[illegible].3	1,441.[illegible]	2,940.8	1,493.2	3,059.1
	Truck (vehicle) operating cost, annual (million dollars)	2,125.8	4,364.3	281.4	568.7	320.5	657.0	491.7	[illegible]93.2	458.4	1,039.5
5. SR	Truck annual average traffic	22,265	29,930	+365	+1,460	365	+365	2,190	2,[illegible]90	2,555	2,555
	Truck-miles, annual (millions)	13,470.0	19,857.5	+142.4	+941.0	178.5	+345.3	1,361.8	1,[illegible]8	1,477.9	1,593.2
	Truck (vehicle) operating cost, annual (million dollars)	4,915.5	7,346.4	+123.7	+466.1	1.1	+234.3	410.6	360.3	458.4	446.8
6. SU	Truck annual average traffic	70,810	81,395	7,300	7,665	8,395	9,125	14,965	16,425	15,330	17,155
	Truck-miles, annual (millions)	1,320.9	2,291.1	138.7	220.8	160.6	262.8	278.5	464.3	288.7	484.4
	Truck (vehicle) operating cost, annual (million dollars)	480.3	839.1	43.4	66.1	51.8	82.9	93.1	153.3	97.5	161.0
All systems (1-6)	Truck annual average traffic	60,955	101,105	5,840	9,125	7,300	12,410	11,680	19,345	12,410	20,805
	Truck-miles, annual (millions)	51,490.5	97,155.4	4,805.6	8,785.6	6,274.3	11,968.6	9,930.1	18,462.2	10,626.2	20,050.3
	Truck (vehicle) operating cost annual (million dollars)	19,240.0	36,889.9	1,227.8	1,940.1	1,810.4	3,201.1	3,090.6	5,476.1	3,370.8	6,101.7

CHAPTER 16

HIGHWAY FINANCING REQUIREMENTS UNDER INCREASED AXLE-WEIGHT LIMITS

Any increase in the legal limits of axle weight would no doubt be accompanied by some additional highway construction cost for the structure of pavements and bridges on existing systems in order to provide the necessary strength to carry the heavier axles that would follow such an increase in axle-weight limits. Therefore, some estimate is called for of the additional financial requirements for highway construction that would result from increased legal limits on axle weight.

1. BASIC CONCEPT AND APPROACH

An estimate of the additional financing required for highway construction under laws permitting higher axle weights can be made by using the material in Chapter 10 as the basis for estimating the additional construction cost per mile of highway. There remains, however, the necessity of estimating the number of miles of existing highway that would be constructed, reconstructed, or resurfaced, in a given time period. It has been assumed that any increase in the allowable weights of axles would result in thicker pavements and stronger bridges, and, therefore, in a greater cost in dollars per mile of highway construction. The analysis of the economy of axle-weight limits indicates the additional costs per mile to be expected.

It is logical to assume that the heavier axle weights, when applied to pavements not specifically designed for such axle weights would cause the pavement to reach a stage warranting reconstruction or resurfacing sooner in calendar time than it would were it not subjected to the higher axle weights.

Since the original pavement design in Chapter 10 was based upon the specific number of E 18-kip axle applications in the 20-year period, the shortening of the service life of the pavement over the years to reach a PSI of 2.0 in 20 years can be calculated by determining the date at which the number of E 18-kip axle applications accumulated would be the same under the higher axle-weight limits as under the lower limits. This time interval, beginning January 1, 1965, was calculated for each of the 5 axle-weight limits at the same time that the computer calculated the pavement design and pavement cost. In calculating the finances required under different levels of axle-weight limits, analysis Method 1-M was used for determining the adjusted average service life and the added cost of construction or reconstruction at the higher limits.

The second major factor that had to be determined was the total miles of highways to be reconstructed each year for the 20 years beginning January 1, 1965. The approach to this estimate was to determine the amount of existing construction on each of the highway systems in terms of the ages, or vintage years, of construction of its several segments and the miles remaining. By applying to the miles of original construction by vintage years a retirement distribution or survivor curve of the appropriate average service life, a theoretical retirement from existing pavements and the miles remaining by ages could be forecasted year by year. Assuming, then, that the retired mileage of pavements would be replaced by reconstruction or resurfacing and that the highway system would be extended by adding lanes and increasing centerline mileage year by year, it is possible to develop a new-construction, reconstruction, and resurfacing program for the 20-year period from 1965 through 1984 for each highway system considered.

In order to apply the basic method, it was necessary to determine by pavement type the lane-miles constructed during each year and the lane-miles existing at the beginning of each year for each highway system and for each of the ten census divisions. Further, it was necessary to determine the shape of the survivor curves and the average service life to be applied to each vintage year of construction by pavement surface type, by highway system, and by census division.

2. ASSEMBLY OF HISTORICAL DATA ON PAVEMENT CONSTRUCTION TO 1964

The forecast of the requirements for pavement replacement from 1965 through 1984 depends upon the age and surface type of pavements existing on January 1, 1965. An estimate of these ages and mileages as of 1965 depends upon the year-by-year constructed mileage in prior years. Therefore, a first step in a projection of construction activity from 1965 through 1984 was to assemble the historical data on construction before 1965.

Data on annual lane-miles of construction by surface types and by census divisions were obtained from construction tabulations furnished by the Program Analysis Division, "Highway Statistics," and other sources. The lane-miles constructed are given for the East North Central census division in table 16-1 together with the type survivor curve and average service life, as an illustration of how the data for each census division were handled.

3. SELECTION OF SURVIVOR CURVES AND SERVICE LIVES

Through the Statewide highway planning surveys, starting in 1935 and continuing to the present, several of the State highway departments made studies to determine the service lives

TABLE 16-1. -- ESTIMATED LANE-MILES OF HIGHWAY CONSTRUCTION AND RELATED TYPE SURVIVOR CURVES 1* FOR FIVE AXLE-WEIGHT LIMITS

CENSUS DIVISION, 5 EAST NORTH CENTRAL

YEAR	LANE-MILES BUILT	TYPE SURVIVOR CURVES FOR EACH SINGLE/TANDEM AXLE-WEIGHT LIMIT				
		18/32	20/35	22/38	24/41	26/44
		SYSTEM 1 INTERSTATE RURAL			SURFACE-TYPE GROUP, 00	
1947	25	S1 12.0	S1 9.4	S1 7.7	S1 6.4	S1 5.5
1949	29	S1 12.0	S1 9.4	S1 7.7	S1 6.4	S1 5.5
1950	103	S1 15.0	S1 11.7	S1 9.6	S1 8.0	S1 6.9
1951	31	S1 15.0	S1 11.7	S1 9.6	S1 8.0	S1 6.9
1952	113	S1 15.0	S1 11.7	S1 9.6	S1 8.0	S1 6.9
1953	180	S1 15.0	S1 11.7	S1 9.6	S1 8.0	S1 6.9
1954	26	S1 15.0	S1 11.7	S1 9.6	S1 8.0	S1 6.9
1955	26	S1 15.0	S1 11.7	S1 9.6	S1 8.0	S1 6.9
1956	31	S1 20.0	S1 15.7	S1 12.8	S1 10.7	S1 9.2
1957	33	S1 20.0	S1 15.7	S1 12.8	S1 10.7	S1 9.2
1960	42	S2 20.0	S2 15.7	S2 12.8	S2 10.7	S2 9.2
1961	35	S2 20.0	S2 15.7	S2 12.8	S2 10.7	S2 9.2
1962	186	S2 20.0	S2 15.7	S2 12.8	S2 10.7	S2 9.2
1963	198	S2 20.0	S2 15.7	S2 12.8	S2 10.7	S2 9.2
1964	168	S2 20.0	S2 15.7	S2 12.8	S2 10.7	S2 9.2
		SYSTEM 1 INTERSTATE RURAL			SURFACE-TYPE GROUP, J	
1947	13	S4 17.0	S4 14.8	S4 13.0	S4 11.5	S4 10.4
1948	32	S4 17.0	S4 14.8	S4 13.0	S4 11.5	S4 10.4
1949	26	S4 17.0	S4 14.8	S4 13.0	S4 11.5	S4 10.4
1950	132	S4 18.0	S4 15.7	S4 13.8	S4 12.2	S4 11.0
1951	121	S4 18.0	S4 15.7	S4 13.8	S4 12.2	S4 11.0
1952	98	S4 18.0	S4 15.7	S4 13.8	S4 12.2	S4 11.0
1953	126	S4 18.0	S4 15.7	S4 13.8	S4 12.2	S4 11.0
1954	215	S4 18.0	S4 15.7	S4 13.8	S4 12.2	S4 11.0
1955	197	S4 20.0	S4 17.4	S4 15.3	S4 13.6	S4 12.2
1956	425	S4 20.0	S4 17.4	S4 15.3	S4 13.6	S4 12.2
1957	259	S6 20.0	S6 17.4	S6 15.3	S6 13.6	S6 12.2
1958	411	S4 20.0	S4 17.4	S4 15.3	S4 13.6	S4 12.2
1959	456	S4 20.0	S4 17.4	S4 15.3	S4 13.6	S4 12.2
1960	1161	S4 20.0	S4 17.4	S4 15.3	S4 13.6	S4 12.2
1961	1142	S4 20.0	S4 17.4	S4 15.3	S4 13.6	S4 12.2
		SYSTEM 2 INTERSTATE URBAN			SURFACE-TYPE GROUP, 00	
1947	3	S1 12.0	S1 11.0	S1 10.1	S1 9.4	S1 8.7
1948	11	S1 12.0	S1 11.0	S1 10.1	S1 9.4	S1 8.7
1949	63	S1 12.0	S1 11.0	S1 10.1	S1 9.4	S1 8.7
1950	34	S1 15.0	S1 13.7	S1 12.6	S1 11.7	S1 10.9
1951	13	S1 15.0	S1 13.7	S1 12.6	S1 11.7	S1 10.9
1952	26	S1 15.0	S1 13.7	S1 12.6	S1 11.7	S1 10.9
1953	34	S1 15.0	S1 13.7	S1 12.6	S1 11.7	S1 10.9
1954	2	S1 15.0	S1 13.7	S1 12.6	S1 11.7	S1 10.9
1955	60	S1 15.0	S1 13.7	S1 12.6	S1 11.7	S1 10.9
1956	29	S1 20.0	S1 18.3	S1 16.9	S1 15.6	S1 14.5
1957	3	S1 20.0	S1 18.3	S1 16.9	S1 15.6	S1 14.5
1958	51	S1 20.0	S1 18.3	S1 16.9	S1 15.6	S1 14.5
1959	13	S1 20.0	S1 18.3	S1 16.9	S1 15.6	S1 14.5
1960	27	S2 20.0	S2 18.3	S2 16.9	S2 15.6	S2 14.5
1961	6	S2 20.0	S2 18.3	S2 16.9	S2 15.6	S2 14.5
1962	2	S2 20.0	S2 18.3	S2 16.9	S2 15.6	S2 14.5
1963	0	S2 20.0	S2 18.3	S2 16.9	S2 15.6	S2 14.5
1964	27	S2 20.0	S2 18.3	S2 16.9	S2 15.6	S2 14.5
		SYSTEM 2 INTERSTATE URBAN			SURFACE-TYPE GROUP, J	
1948	2	S4 17.0	S4 15.7	S4 14.5	S4 13.5	S4 12.6
1949	27	S4 17.0	S4 15.7	S4 14.5	S4 13.5	S4 12.6
1950	26	S4 18.0	S4 16.6	S4 15.4	S4 14.3	S4 13.3
1951	25	S4 18.0	S4 16.6	S4 15.4	S4 14.3	S4 13.3
1952	77	S4 18.0	S4 16.6	S4 15.4	S4 14.3	S4 13.3
1953	91	S4 18.0	S4 16.6	S4 15.4	S4 14.3	S4 13.3
1954	15	S4 18.0	S4 16.6	S4 15.4	S4 14.3	S4 13.3
1955	74	S4 20.0	S4 18.4	S4 17.1	S4 15.8	S4 14.8
1956	41	S4 20.0	S4 18.4	S4 17.1	S4 15.8	S4 14.8
1957	134	S6 20.0	S6 18.4	S6 17.1	S6 15.8	S6 14.8
1958	31	S4 20.0	S4 18.4	S4 17.1	S4 15.8	S4 14.8
1959	87	S4 20.0	S4 18.4	S4 17.1	S4 15.8	S4 14.8
1960	88	S4 20.0	S4 18.4	S4 17.1	S4 15.8	S4 14.8
1961	148	S4 20.0	S4 18.4	S4 17.1	S4 15.8	S4 14.8
1962	108	S4 20.0	S4 18.4	S4 17.1	S4 15.8	S4 14.8
1963	122	S3 20.0	S3 18.4	S3 17.1	S3 15.8	S3 14.8
1964	279	S3 20.0	S3 18.4	S3 17.1	S3 15.8	S3 14.8

1* THE DESIGNATION SUCH AS L3-20 INDICATES AN L3 SHAPE OF THE CURVE AND A 20 YEARS AVERAGE SERVICE LIFE.

TABLE 16-1. -- ESTIMATED LANE-MILES OF HIGHWAY CONSTRUCTION AND RELATED TYPE SURVIVOR CURVES 1*
FOR FIVE AXLE-WEIGHT LIMITS

CENSUS DIVISION, 5 EAST NORTH CENTRAL

SYSTEM 3 FEDERAL-AID PRIMARY RURAL — SURFACE-TYPE GROUP, F

YEAR	LANE-MILES BUILT	TYPE SURVIVOR CURVES FOR EACH SINGLE/TANDEM AXLE-WEIGHT LIMIT 18/32	20/35	22/38	24/41	26/44
1923	547	S3 7.0	S3 6.1	S3 5.3	S3 4.7	S3 4.2
1924	6	S2 8.0	S2 7.0	S2 6.1	S2 5.4	S2 4.8
1925	68	S4 8.0	S4 7.0	S4 6.1	S4 5.4	S4 4.8
1926	118	L3 6.0	L3 5.2	L3 4.6	L3 4.0	L3 3.6
1927	214	L3 5.0	L3 4.3	L3 3.8	L3 3.4	L3 3.0
1928	58	S3 9.0	S3 7.8	S3 6.9	S3 6.1	S3 5.4
1929	82	S3 5.0	S3 4.3	S3 3.8	S3 3.4	S3 3.0
1930	58	S3 5.0	S3 4.3	S3 3.8	S3 3.4	S3 3.0
1931	54	S3 5.0	S3 4.3	S3 3.8	S3 3.4	S3 3.0
1932	38	L1 5.0	L1 4.3	L1 3.8	L1 3.4	L1 3.0
1933	12	L1 5.0	L1 4.3	L1 3.8	L1 3.4	L1 3.0
1934	268	L1 5.0	L1 4.3	L1 3.8	L1 3.4	L1 3.0
1935	342	L1 5.0	L1 4.3	L1 3.8	L1 3.4	L1 3.0
1936	320	L1 5.0	L1 4.3	L1 3.8	L1 3.4	L1 3.0
1937	376	L1 9.0	L1 7.8	L1 6.9	L1 6.1	L1 5.4
1938	1044	L4 9.0	L4 7.8	L4 6.9	L4 6.1	L4 5.4
1939	768	L5 9.0	L5 7.8	L5 6.9	L5 6.1	L5 5.4
1940	350	L2 6.0	L2 5.2	L2 4.6	L2 4.0	L2 3.6
1941	372	L1 8.0	L1 7.0	L1 6.1	L1 5.4	L1 4.8
1942	442	L1 7.0	L1 6.1	L1 5.3	L1 4.7	L1 4.2
1943	452	L1 8.0	L1 7.0	L1 6.1	L1 5.4	L1 4.8
1944	590	L1 7.0	L1 6.1	L1 5.3	L1 4.7	L1 4.2
1945	436	L2 7.0	L2 6.1	L2 5.3	L2 4.7	L2 4.2
1946	468	L1 7.0	L1 6.1	L1 5.3	L1 4.7	L1 4.2
1947	570	S3 7.0	S3 6.1	S3 5.3	S3 4.7	S3 4.2
1948	530	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1949	556	S2 10.0	S2 8.7	S2 7.6	S2 6.7	S2 6.0
1950	546	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1951	490	L1 12.0	L1 10.4	L1 9.2	L1 8.1	L1 7.3
1952	399	L1 14.0	L1 12.2	L1 10.7	L1 9.4	L1 8.5
1953	428	L1 14.0	L1 12.2	L1 10.7	L1 9.4	L1 8.5
1954	476	L1 14.0	L1 12.2	L1 10.7	L1 9.4	L1 8.5
1955	544	L2 10.0	L2 8.7	L2 7.6	L2 6.7	L2 6.0
1956	414	L2 10.0	L2 8.7	L2 7.6	L2 6.7	L2 6.0
1957	410	L2 10.0	L2 8.7	L2 7.6	L2 6.7	L2 6.0
1958	236	L2 10.0	L2 8.7	L2 7.6	L2 6.7	L2 6.0
1959	400	L2 10.0	L2 8.7	L2 7.6	L2 6.7	L2 6.0
1960	318	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1961	290	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1962	166	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1963	127	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1964	61	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0

1* THE DESIGNATION SUCH AS L3-20 INDICATES AN L3 SHAPE OF THE CURVE AND A 20 YEARS AVERAGE SERVICE LIFE.

TABLE 16-1. -- ESTIMATED LANE-MILES OF HIGHWAY CONSTRUCTION AND RELATED TYPE SURVIVOR CURVES 1• FOR FIVE AXLE WEIGHT LIMITS

CENSUS DIVISION, 5 EAST NORTH CENTRAL

YEAR	LANE-MILES BUILT	TYPE SURVIVOR CURVES FOR EACH SINGLE/TANDEM AXLE-WEIGHT LIMIT				
		18/32	20/35	22/38	24/41	26/44
		SYSTEM 3 FEDERAL-AID PRIMARY RURAL			SURFACE-TYPE GROUP, OO	
1923	4671	S3 14.0	S3 12.2	S3 10.7	S3 9.4	S3 8.5
1924	7549	S3 21.0	S3 18.3	S3 16.0	S3 14.2	S3 12.7
1925	7768	R3 16.0	R3 13.9	R3 12.2	R3 10.8	R3 9.7
1926	4491	R3 17.0	R3 14.8	R3 13.0	R3 11.5	R3 10.3
1927	9224	S3 14.0	S3 12.2	S3 10.7	S3 9.4	S3 8.5
1928	6030	S3 14.0	S3 12.2	S3 10.7	S3 9.4	S3 8.5
1929	886	S3 11.0	S3 9.6	S3 8.4	S3 7.4	S3 6.6
1930	931	R4 13.0	R4 11.3	R4 9.9	R4 8.8	R4 7.9
1931	938	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1932	1012	S3 13.0	S3 11.3	S3 9.9	S3 8.8	S3 7.9
1933	987	L3 11.0	L3 9.6	L3 8.4	L3 7.4	L3 6.6
1934	1146	L3 10.0	L3 8.7	L3 7.6	L3 6.7	L3 6.0
1935	1032	S3 12.0	S3 10.4	S3 9.2	S3 8.1	S3 7.3
1936	1319	S3 16.0	S3 13.9	S3 12.2	S3 10.8	S3 9.7
1937	1320	S3 14.0	S3 12.2	S3 10.7	S3 9.4	S3 8.5
1938	1295	S3 12.0	S3 10.4	S3 9.2	S3 8.1	S3 7.3
1939	1294	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1940	1413	S2 13.0	S2 11.3	S2 9.9	S2 8.8	S2 7.9
1941	1555	S2 12.0	S2 10.4	S2 9.2	S2 8.1	S2 7.3
1942	1416	S3 10.0	S3 8.7	S3 7.6	S3 6.7	S3 6.0
1943	1671	S3 14.0	S3 12.2	S3 10.7	S3 9.4	S3 8.5
1944	1649	S3 15.0	S3 13.0	S3 11.4	S3 10.1	S3 9.1
1945	1527	S3 12.0	S3 10.4	S3 9.2	S3 8.1	S3 7.3
1946	1734	S3 14.0	S3 12.2	S3 10.7	S3 9.4	S3 8.5
1947	3124	S2 15.0	S2 13.0	S2 11.4	S2 10.1	S2 9.1
1948	2777	S3 13.0	S3 11.3	S3 9.9	S3 8.8	S3 7.9
1949	2982	S2 13.0	S2 11.3	S2 9.9	S2 8.8	S2 7.9
1950	2201	S1 14.0	S1 12.2	S1 10.7	S1 9.4	S1 8.5
1951	2189	S2 13.0	S2 11.3	S2 9.9	S2 8.8	S2 7.9
1952	2391	S2 13.0	S2 11.3	S2 9.9	S2 8.8	S2 7.9
1953	1889	S1 12.0	S1 10.4	S1 9.2	S1 8.1	S1 7.3
1954	2296	S1 12.0	S1 10.4	S1 9.2	S1 8.1	S1 7.3
1955	2256	S1 11.0	S1 9.6	S1 8.4	S1 7.4	S1 6.6
1956	2541	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1957	3192	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1958	4462	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1959	3189	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1960	4250	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1961	3252	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1962	2949	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1963	2702	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7
1964	1345	S2 16.0	S2 13.9	S2 12.2	S2 10.8	S2 9.7

1• THE DESIGNATION SUCH AS L3-20 INDICATES AN L3 SHAPE OF THE CURVE AND A 20 YEARS AVERAGE SERVICE LIFE.

TABLE 16-1. -- ESTIMATED LANE-MILES OF HIGHWAY CONSTRUCTION AND RELATED TYPE SURVIVOR CURVES 1* FOR FIVE AXLE-WEIGHT LIMITS

CENSUS DIVISION, 5 EAST NORTH CENTRAL

YEAR	LANE-MILES BUILT	TYPE SURVIVOR CURVES FOR EACH SINGLE/TANDEM AXLE-WEIGHT LIMIT				
		18/32	20/35	22/38	24/41	26/44
		SYSTEM 3 FEDERAL-AID PRIMARY RURAL			SURFACE-TYPE GROUP, J	
1923	3033	S3 29.0	S3 28.3	S3 27.5	S3 26.9	S3 26.3
1924	2286	S4 28.0	S4 27.3	S4 26.6	S4 25.9	S4 25.4
1925	1368	S3 28.0	S3 27.3	S3 26.6	S3 25.9	S3 25.4
1926	1112	S3 27.0	S3 26.3	S3 25.6	S3 25.0	S3 24.4
1927	1232	L3 28.0	L3 27.3	L3 26.6	L3 25.9	L3 25.4
1928	2088	L4 28.0	L4 27.3	L4 26.6	L4 25.9	L4 25.4
1929	1788	S3 26.0	S3 25.3	S3 24.7	S3 24.1	S3 23.5
1930	2196	S3 26.0	S3 25.3	S3 24.7	S3 24.1	S3 23.5
1931	2106	R3 28.0	R3 27.3	R3 26.6	R3 25.9	R3 25.4
1932	2128	S3 26.0	S3 25.3	S3 24.7	S3 24.1	S3 23.5
1933	1350	R3 27.0	R3 26.3	R3 25.6	R3 25.0	R3 24.4
1934	656	R3 27.0	R3 26.3	R3 25.6	R3 25.0	R3 24.4
1935	306	R3 25.0	R3 24.4	R3 23.7	R3 23.2	R3 22.6
1936	258	R3 23.0	R3 22.4	R3 21.8	R3 21.3	R3 20.8
1937	640	R3 25.0	R3 24.4	R3 23.7	R3 23.2	R3 22.6
1938	258	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1939	380	S3 28.0	S3 27.3	S3 26.6	S3 25.9	S3 25.4
1940	118	S3 28.0	S3 27.3	S3 26.6	S3 25.9	S3 25.4
1941	260	S3 18.0	S3 17.5	S3 17.1	S3 16.7	S3 16.3
1942	160	S3 18.0	S3 17.5	S3 17.1	S3 16.7	S3 16.3
1943	36	S3 16.0	S3 15.6	S3 15.2	S3 14.8	S3 14.5
1944	126	S3 15.0	S3 14.6	S3 14.2	S3 13.9	S3 13.6
1945	136	S3 26.0	S3 25.3	S3 24.7	S3 24.1	S3 23.5
1946	120	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1947	735	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1948	1187	S3 18.0	S3 17.5	S3 17.1	S3 16.7	S3 16.3
1949	1289	S1 19.0	S1 18.5	S1 18.0	S1 17.6	S1 17.2
1950	1496	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1951	1531	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1952	1763	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1953	1137	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1954	1347	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1955	1227	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1956	1407	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1957	1130	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1958	382	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1959	617	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1960	695	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1961	364	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1962	562	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1963	1021	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
1964	213	S3 20.0	S3 19.5	S3 19.0	S3 18.5	S3 18.1
		SYSTEM 4 FEDERAL-AID PRIMARY URBAN			SURFACE-TYPE GROUP, F	
1934	10	L1 5.0	L1 4.3	L1 3.7	L1 3.3	L1 3.0
1937	45	L1 9.0	L1 7.7	L1 6.7	L1 6.0	L1 5.4
1938	34	L4 9.0	L4 7.7	L4 6.7	L4 6.0	L4 5.4
1939	6	L5 9.0	L5 7.7	L5 6.7	L5 6.0	L5 5.4
1940	3	L2 6.0	L2 5.1	L2 4.5	L2 4.0	L2 3.6
1941	2	L1 8.0	L1 6.9	L1 6.0	L1 5.3	L1 4.8
1942	1	L1 7.0	L1 6.0	L1 5.2	L1 4.6	L1 4.2
1943	3	L1 8.0	L1 6.9	L1 6.0	L1 5.3	L1 4.8
1944	6	L1 6.0	L1 5.1	L1 4.5	L1 4.0	L1 3.6
1945	10	L4 7.0	L4 6.0	L4 5.2	L4 4.6	L4 4.2
1946	10	L1 7.0	L1 6.0	L1 5.2	L1 4.6	L1 4.2
1948	10	S3 7.0	S3 6.0	S3 5.2	S3 4.6	S3 4.2
1949	22	S2 8.0	S2 6.9	S2 6.0	S2 5.3	S2 4.8
1951	14	S3 10.0	S3 8.6	S3 7.5	S3 6.6	S3 6.0
1952	5	L1 14.0	L1 12.0	L1 10.5	L1 9.3	L1- 8.3
1957	18	L1 14.0	L1 12.0	L1 10.5	L1 9.3	L1 8.3
1958	6	L1 14.0	L1 12.0	L1 10.5	L1 9.3	L1 8.3
1959	4	L2 8.0	L2 6.9	L2 6.0	L2 5.3	L2 4.8
1960	6	S3 10.0	S3 8.6	S3 7.5	S3 6.6	S3 6.0
1963	0	S3 10.0	S3 8.6	S3 7.5	S3 6.6	S3 6.0
1964	3	S3 10.0	S3 8.6	S3 7.5	S3 6.6	S3 6.0

1* THE DESIGNATION SUCH AS L3-20 INDICATES AN L3 SHAPE OF THE CURVE AND A 20 YEARS AVERAGE SERVICE LIFE.

TABLE 16-1. -- ESTIMATED LANE-MILES OF HIGHWAY CONSTRUCTION AND RELATED TYPE SURVIVOR CURVES 1• FOR FIVE AXLE WEIGHT LIMITS

CENSUS DIVISION, 5 EAST NORTH CENTRAL

SYSTEM 4 FEDERAL-AID PRIMARY URBAN SURFACE-TYPE GROUP, OO

YEAR	LANE-MILES BUILT	TYPE SURVIVOR CURVES FOR EACH SINGLE/TANDEM AXLE WEIGHT LIMIT 18/32	20/35	22/38	24/41	26/44
1934	2724	L3 10.0	L3 8.6	L3 7.5	L3 6.6	L3 6.0
1935	89	S3 12.0	S3 10.3	S3 9.0	S3 7.9	S3 7.2
1936	111	S3 12.0	S3 10.3	S3 9.0	S3 7.9	S3 7.2
1937	103	S3 14.0	S3 12.0	S3 10.5	S3 9.3	S3 8.3
1938	99	S3 12.0	S3 10.3	S3 9.0	S3 7.9	S3 7.2
1939	253	S3 10.0	S3 8.6	S3 7.5	S3 6.6	S3 6.0
1940	277	S2 13.0	S2 11.1	S2 9.7	S2 8.6	S2 7.7
1941	253	S2 10.0	S2 8.6	S2 7.5	S2 6.6	S2 6.0
1942	231	S3 10.0	S3 8.6	S3 7.5	S3 6.6	S3 6.0
1943	297	S3 14.0	S3 12.0	S3 10.5	S3 9.3	S3 8.3
1944	457	S3 15.0	S3 12.9	S3 11.2	S3 9.9	S3 8.9
1945	419	S3 9.0	S3 7.7	S3 6.7	S3 6.0	S3 5.4
1946	755	S4 14.0	S4 12.0	S4 10.5	S4 9.3	S4 8.3
1947	374	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1948	350	S3 11.0	S3 9.4	S3 8.2	S3 7.3	S3 6.6
1949	398	S2 11.0	S2 9.4	S2 8.2	S2 7.3	S2 6.6
1950	440	S1 14.0	S1 12.0	S1 10.5	S1 9.3	S1 8.3
1951	299	S2 13.0	S2 11.1	S2 9.7	S2 8.6	S2 7.7
1952	338	S2 13.0	S2 11.1	S2 9.7	S2 8.6	S2 7.7
1953	232	S1 10.0	S1 8.6	S1 7.5	S1 6.6	S1 6.0
1954	366	S1 10.0	S1 8.6	S1 7.5	S1 6.6	S1 6.0
1955	424	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1956	457	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1957	685	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1958	614	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1959	745	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1960	228	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1961	1112	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1962	490	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1963	476	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9
1964	458	S2 15.0	S2 12.9	S2 11.2	S2 9.9	S2 8.9

SYSTEM 4 FEDERAL-AID PRIMARY URBAN SURFACE-TYPE GROUP, J

YEAR	LANE-MILES BUILT	18/32	20/35	22/38	24/41	26/44
1934	420	R3 27.0	R3 26.3	R3 25.5	R3 24.8	R3 24.2
1935	214	R3 25.0	R3 24.3	R3 23.6	R3 23.0	R3 22.4
1936	262	R3 23.0	R3 22.4	R3 21.8	R3 21.2	R3 20.6
1937	260	R3 25.0	R3 24.3	R3 23.6	R3 23.0	R3 22.4
1938	198	S4 16.0	S4 15.6	S4 15.1	S4 14.7	S4 14.4
1939	266	S4 31.0	S4 30.1	S4 29.3	S4 28.5	S4 27.8
1940	180	S3 31.0	S3 30.1	S3 29.3	S3 28.5	S3 27.8
1941	214	S3 17.0	S3 16.5	S3 16.1	S3 15.6	S3 15.3
1942	172	S3 17.0	S3 16.5	S3 16.1	S3 15.6	S3 15.3
1943	74	S3 16.0	S3 15.6	S3 15.1	S3 14.7	S3 14.4
1944	106	S3 16.0	S3 15.6	S3 15.1	S3 14.7	S3 14.4
1945	148	S4 26.0	S4 25.3	S4 24.6	S4 23.9	S4 23.3
1946	134	S6 14.0	S6 13.6	S6 13.2	S6 12.9	S6 12.6
1947	24	S4 17.0	S4 16.5	S4 16.1	S4 15.6	S4 15.3
1948	74	S4 17.0	S4 16.5	S4 16.1	S4 15.6	S4 15.3
1949	144	S4 17.0	S4 16.5	S4 16.1	S4 15.6	S4 15.3
1950	130	S1 19.0	S1 18.5	S1 18.0	S1 17.5	S1 17.1
1951	117	S3 20.0	S3 19.4	S3 18.9	S3 18.4	S3 18.0
1952	106	S3 20.0	S3 19.4	S3 18.9	S3 18.4	S3 18.0
1953	128	S3 20.0	S3 19.4	S3 18.9	S3 18.4	S3 18.0
1954	154	S3 20.0	S3 19.4	S3 18.9	S3 18.4	S3 18.0
1955	176	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1956	239	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1957	154	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1958	238	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1959	311	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1960	300	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1961	298	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1962	366	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1963	256	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0
1964	259	S4 20.0	S4 19.4	S4 18.9	S4 18.4	S4 18.0

1• THE DESIGNATION SUCH AS L3-20 INDICATES AN L3 SHAPE OF THE CURVE AND A 20 YEARS AVERAGE SERVICE LIFE.

in years of their pavements by surface type. By reference to these reports in the files of the Bureau of Public Roads and to published papers, a selection of typical survivor curves and service lives was made for each vintage of construction from 1920 to 1964 for each of the four highway systems and ten census divisions. Table 16-1 indicates the final selections for the East North Central census division. The word final is used because in some cases it was necessary to run some preliminary calculations to test the validity of the survivor-curve selection, as explained in a later section of this report. Adjustments were made to accomplish approximate agreement of the calculated lane-miles of pavement surviving with the lane-miles surviving as of January 1, 1965 as reported in "Highway Statistics."

The so-called "road life" studies, which have been carried on by several State highway departments, used as their basic references a technique published in 1935 by the Iowa State College Engineering Experiment Station under the title, "Statistical Analyses of Industrial Property Retirements." In this publication, 18 typical survivor curves were developed for a variety of physical properties. These curves are shown in figures 16-1, 16-2, and 16-3.

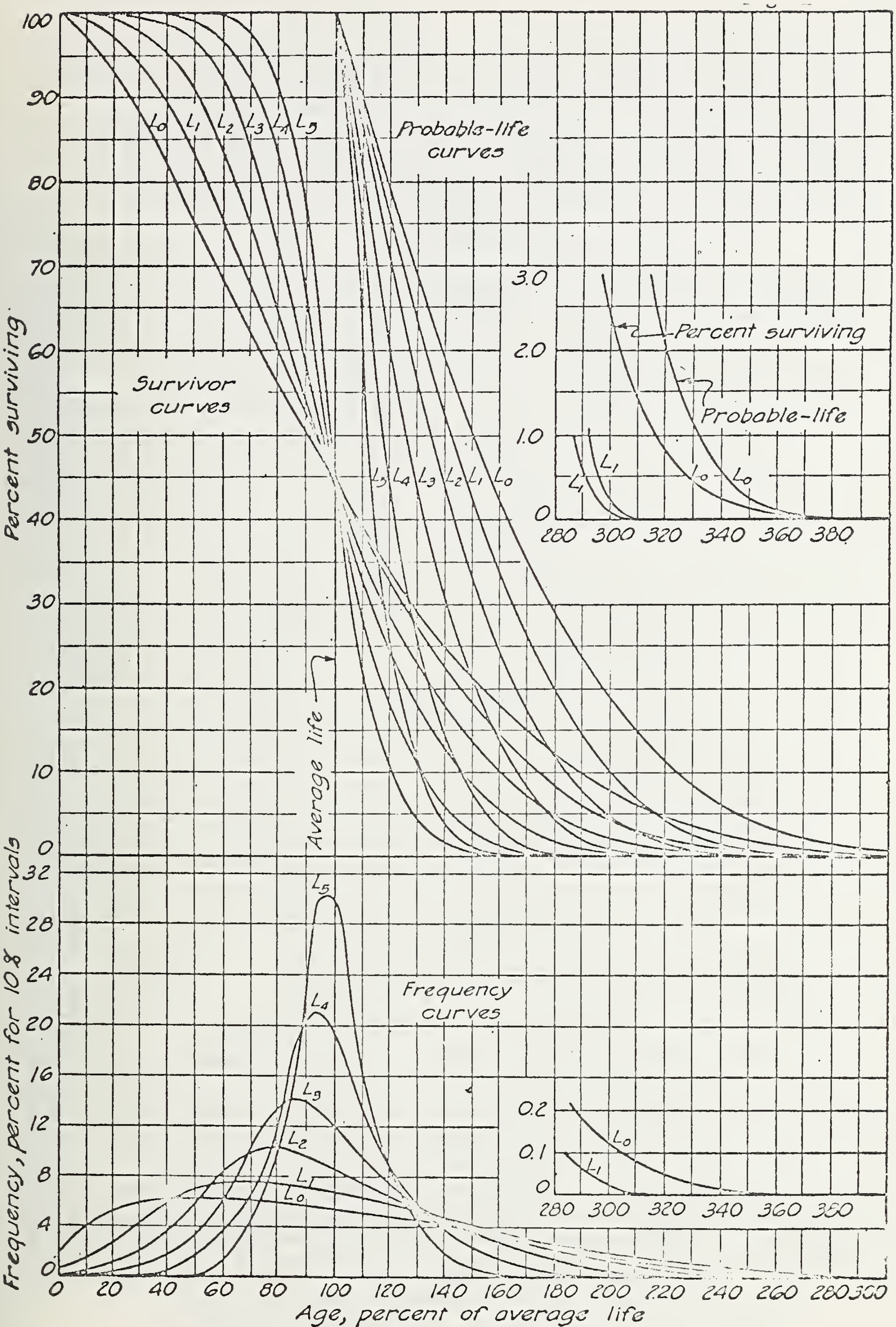

Figure 16-1. -- The left-modal type survivor curves.

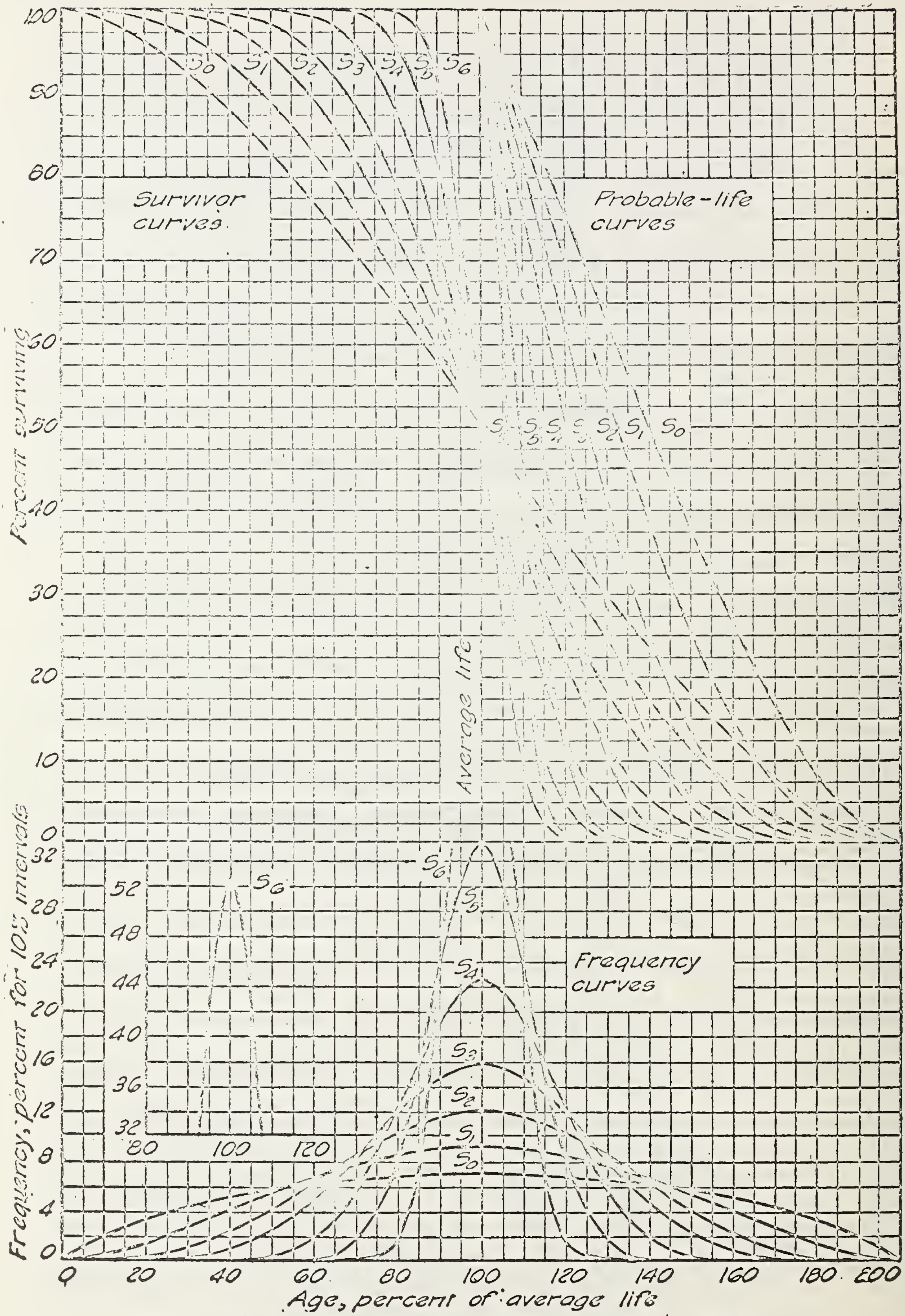

Figure 16-2. -- The symmetrical type survivor curves.

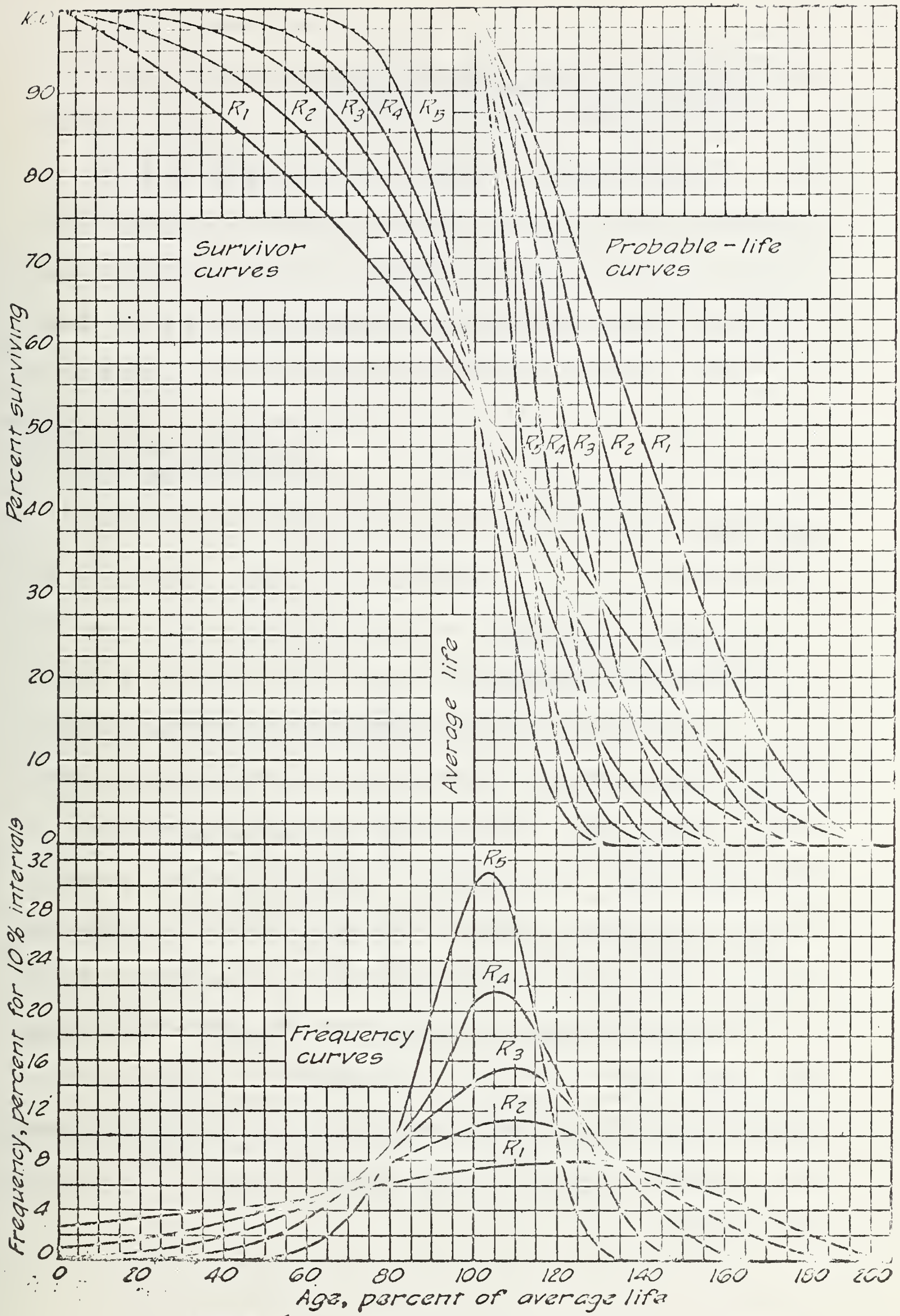

Figure 16-3. -- The right modal type survivor curves.

4. PROJECTION TO 1984 OF THE YEARLY LANE-MILES CONSTRUCTED AND SURVIVING UNDER THE BASE AXLE-WEIGHT LIMITS

By applying the survivor-curve selections to the historical year-by-year construction by surface types, a forecast of the lane-miles of construction prior to 1965 that would survive in service yearly from 1965 through 1984 was obtained. To estimate the total yearly construction from 1965 through 1984 requires an estimate of theyearly extensions of the system in lane-miles existing in addition to the retirements (to be replaced) as obtained from the calculations of the surviving lane-miles.

A. Lane-miles in Service Yearly 1965 through 1984

In conformity with past experience, the mileage of a given highway system may be expected to increase more or less yearly, 1965 to 1984. This increase in centerline mileage (and lane mileage) would require, in addition to reconstruction and resurfacing, yearly construction replacing retirements. In order to provide for such extensions of the highway systems, a "control lane mileage" was established for each surface type. The overall system mileage for the Federal-aid primary system from 1965 to 1984 was established in approximate conformity with the forecasted increase in vehicle-miles of travel that was used in Chapter 10.

The control lane-miles by surface type, given in table 16-2, were set on the basis that the low and intermediate types would be replaced with high-type pavement and that the mileage of high-type pavement would increase. Some adjustments of the first estimates of future control lane-miles, selected survivor curves, and past annual construction were necessary in order to produce a reasonable number of existing lane-miles year by year from 1965 to 1984.

B. Control Lane-miles by Surface Types

Surface-type classifications for 1965 to 1985 are based on the overall average for the period 1960 through 1984. In the event that control mileage for a particular surface type tended to decrease, the input control was held constant at the 1964 level. This action was required because of the manner in which the computer program was written. The projected decrease in surface-type mileage was provided for by scheduling the retirements for replacement by surfaces of a higher type without changing the classification used by the computer. Such decreases in control mileage occur in the lower surface-type group (F) and represent changes to higher surface types. Therefore, these retirements during the 1965 to 1984 projected period are priced at the construction cost of the high type of surface.

TABLE 16-2. -- PROJECTED LANE-MILES OF HIGHWAYS IN SERVICE
DECEMBER 31, 1964 THROUGH 1984 BY CENSUS DIVISION AND SURFACE TYPE[1/]

Sheet 1 of 4

SYSTEM 1, INTERSTATE RURAL

YEAR	CENSUS DIVISION									
	1. NE	2. MA	3. SAN	4. SAS	5. ENC	6. WNC	7. ESC	8. WSC	9. M	10. P
	SURFACE-TYPE GROUP F[2/]									
1964	0	0	0	309	0	0	0	288	873	0
1965	0	0	0	309	0	0	0	288	873	0
1966	0	0	0	309	0	0	0	288	873	0
1967	0	0	0	309	0	0	0	288	873	0
1968	0	0	0	309	0	0	0	288	873	0
1969	0	0	0	309	0	0	0	288	873	0
1970	0	0	0	309	0	0	0	288	873	0
1971	0	0	0	309	0	0	0	288	873	0
1972	0	0	0	309	0	0	0	288	873	0
1973	0	0	0	309	0	0	0	288	873	0
1974	0	0	0	309	0	0	0	288	873	0
1975	0	0	0	309	0	0	0	288	873	0
1976	0	0	0	309	0	0	0	288	873	0
1977	0	0	0	309	0	0	0	288	873	0
1978	0	0	0	309	0	0	0	288	873	0
1979	0	0	0	309	0	0	0	288	873	0
1980	0	0	0	309	0	0	0	288	873	0
1981	0	0	0	309	0	0	0	288	873	0
1982	0	0	0	309	0	0	0	288	873	0
1983	0	0	0	309	0	0	0	288	873	0
1984	0	0	0	309	0	0	0	288	873	0
	SURFACE-TYPE GROUP GO									
1964	1333	516	931	2948	1014	1623	2379	3626	9888	2942
1965	1555	629	1287	3659	1144	2000	3250	4180	11009	3637
1966	1777	742	1644	4370	1274	2360	3850	4553	12669	4228
1967	1999	854	2001	5081	1404	2720	4450	5727	14329	4819
1968	2220	966	2358	5792	1535	3100	5025	6501	15989	5410
1969	2441	1078	2715	6504	1666	3460	5575	7275	17649	6001
1970	2662	1190	3072	7216	1797	3810	6125	8049	19309	6592
1971	2883	1302	3429	7928	1928	4180	6675	8787	20969	7183
1972	3104	1414	3786	8640	2059	4558	7222	9525	22629	7773
1973	3318	1509	4122	9421	2202	4949	7884	10343	24683	8461
1974	3533	1605	4458	10201	2346	5340	8546	11161	26737	9148
1975	3749	1701	4791	10979	2489	5733	9212	11984	28790	9837
1976	3839	1749	4850	11238	2527	5853	9400	12322	29777	10154
1977	3928	1796	4909	11497	2564	5974	9589	12660	30762	10470
1978	4018	1843	4968	11757	2602	6094	9778	12999	31748	10788
1979	4108	1891	5027	12017	2640	6214	9967	13337	32733	11105
1980	4197	1938	5086	12276	2677	6335	10155	13675	33719	11421
1981	4287	1985	5145	12535	2715	6455	10344	14013	34704	11738
1982	4377	2033	5204	12794	2753	6576	10533	14351	35691	12055
1983	4466	2080	5263	13054	2790	6696	10722	14690	36676	12371
1984	4555	2127	5322	13313	2828	6816	10910	15028	37662	12688
	SURFACE-TYPE GROUP J									
1964	468	2087	576	1628	7758	6293	1801	2725	1333	1755
1965	564	2532	781	1952	8950	7191	2268	3013	1521	2217
1966	660	2976	986	2276	10050	8089	2640	3416	1670	2610
1967	756	3420	1191	2600	11100	8987	2980	3819	1819	3003
1968	852	3864	1396	2924	12075	9885	3280	4223	1967	3396
1969	948	4308	1601	3248	13025	10783	3575	4627	2115	3789
1970	1044	4752	1806	3573	13975	11681	3850	5031	2263	4182
1971	1140	5196	2011	3898	14925	12579	4125	5416	2411	4575
1972	1235	5640	2217	4223	15861	13480	4392	5801	2559	4968
1973	1320	6021	2413	4604	16965	14635	4794	6299	2791	5407
1974	1405	6402	2610	4986	18068	15791	5197	6798	3023	5847
1975	1492	6786	2805	5366	19173	16955	5602	7298	3256	6288
1976	1527	6974	2840	5493	19463	17311	5717	7504	3367	6490
1977	1563	7164	2875	5620	19754	17667	5832	7711	3479	6694
1978	1599	7353	2909	5746	20044	18023	5946	7916	3590	6895
1979	1634	7541	2944	5873	20334	18379	6061	8122	3702	7097
1980	1670	7730	2979	6000	20625	18735	6176	8328	3813	7300
1981	1706	7920	3013	6127	20915	19091	6291	8535	3925	7502
1982	1721	8108	3048	6254	21205	19447	6405	8741	4036	7704
1983	1777	8297	3082	6380	21496	19803	6520	8946	4148	7907
1984	1813	8486	3117	6507	21786	20159	6635	9153	4259	8109

1/ The projections from 1964 to 1972 are based on estimated 1972 system lane-miles obtained from the Interstate Reports Branch. Projections to years after 1972 have been based on estimated vehicle-miles of travel on the system from the Planning Services Branch.

2/ Type F was phased out as retired and replaced by higher type flexible pavement. The original 1964 lane-miles were carried forward to avoid adjusting the computer program.

TABLE 16-2. -- PROJECTED LANE-MILES OF HIGHWAYS IN SERVICE DECEMBER 31, 1964 THROUGH 1984 BY CENSUS DIVISION AND SURFACE TYPE[1]

Sheet 2 of 4

SYSTEM 2, INTERSTATE URBAN

YEAR	CENSUS DIVISION									
	1. NE	2. MA	3. SAN	4. SAS	5. ENC	6. WNC	7. ESC	8. WSC	9. M	10. P
	SURFACE-TYPE GROUP F[2]									
1964	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	C	0	0
1968	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	C	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	C	0	0
1975	0	0	0	0	0	0	0	C	0	0
1976	0	0	0	0	0	0	0	0	0	0
1977	C	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	C	0	0
1984	0	0	0	0	0	0	0	0	0	0
	SURFACE-TYPE GROUP OO									
1964	414	257	109	481	288	152	226	786	357	398
1965	524	316	165	551	350	208	261	929	461	493
1966	634	375	221	621	435	249	312	1112	565	588
1967	744	435	277	691	540	290	377	1296	669	683
1968	854	495	333	762	665	331	449	1480	773	778
1969	964	555	390	833	795	372	530	1664	877	873
1970	1C74	615	447	904	940	413	617	1848	981	968
1971	1183	675	504	975	1090	453	709	2C25	1085	1063
1972	1292	735	561	1046	1254	493	801	2203	1192	1162
1973	1392	781	613	1139	1355	535	874	2387	1301	1248
1974	1495	827	664	1231	1457	576	948	2571	1410	1335
1975	1596	873	717	1325	1558	618	1021	2755	1523	1421
1976	1634	9C0	739	1392	1612	635	1065	2833	1581	1452
1977	1672	928	761	1460	1666	652	11C8	2911	1640	1483
1978	1711	955	783	1527	1719	669	1151	2989	1699	1514
1979	1749	983	805	1595	1773	686	1194	3C68	1757	1545
1980	1787	1010	827	1663	1827	703	1237	3146	1816	1576
1981	1825	1037	849	1731	188C	720	1280	3224	1874	1606
1982	1863	1065	872	1798	1934	737	1323	3302	1933	1637
1983	1902	1092	894	1866	1987	754	1367	338C	1992	1668
1984	1940	1120	916	1933	2041	771	1409	3458	2050	1699
	SURFACE-TYPE GROUP J									
1964	174	934	306	463	1356	1065	380	1C19	193	1823
1965	231	1155	450	495	1586	1226	419	1154	234	2116
1966	288	1376	594	527	1886	1343	477	1328	275	2409
1967	345	1597	738	560	2230	1460	547	1502	316	2702
1968	402	1818	882	593	2600	1577	627	1676	357	2995
1969	459	2040	1027	626	3000	1694	713	1850	398	3288
1970	516	2262	1172	659	3400	1814	809	2C25	439	3581
1971	572	2484	1317	692	3830	1928	908	2193	480	3874
1972	628	2706	1462	725	4269	2045	1009	2361	522	4172
1973	678	2875	1596	789	4615	2217	1102	2558	570	4483
1974	726	3043	1732	854	4959	2391	1195	2755	618	4793
1975	776	3212	1867	918	5306	2566	1287	2952	667	5103
1976	794	3314	1925	965	5488	2636	1341	3C36	693	5214
1977	813	3415	1983	1012	5670	2706	1395	3120	718	5325
1978	831	3516	2041	1059	5854	2777	1450	3204	744	5435
1979	850	3617	2099	11C6	6036	2847	1504	3287	770	5546
1980	869	3718	2157	1152	6218	2917	1559	3371	795	5657
1981	887	3820	2214	1199	6401	2987	1613	3455	821	5768
1982	906	3921	2271	1246	6583	3068	1667	3539	846	5879
1983	924	4022	2329	1293	6766	3128	1721	3623	872	5989
1984	943	4123	2387	1340	6948	3198	1776	3707	898	6100

1/ The projections from 1964 to 1972 are based on estimated 1972 system lane-miles obtained from the Interstate Reports Branch. Projections to years after 1972 have been based on estimated vehicle-miles of travel on the system from the Planning Services Branch.

2/ Type F was phased out as retired and replaced by higher type flexible pavement. The original 1964 lane-miles were carried forward to avoid adjusting the computer program.

TABLE 16-2. -- PROJECTED LANE-MILES OF HIGHWAYS IN SERVICE
DECEMBER 31, 1964 THROUGH 1984 BY CENSUS DIVISION AND SURFACE TYPE[1]

Sheet 3 of 4

SYSTEM 3, FEDERAL-AID PRIMARY RURAL

YEAR	CENSUS DIVISION									
	1. NE	2. MA	3. SAN	4. SAS	5. ENC	6. WNC	7. ESC	8. WSC	9. M	10. P
SURFACE-TYPE GROUP F[2]										
1964	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1965	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1966	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1967	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1968	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1969	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1970	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1971	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1972	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1973	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1974	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1975	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1976	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1977	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1978	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1979	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1980	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1981	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1982	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1983	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
1984	2786	4302	1573	7560	3266	25371	7409	11368	7622	6405
SURFACE-TYPE GROUP GO										
1964	7682	16065	12216	25258	37096	37466	23067	32919	32589	18025
1965	7930	16325	12360	25765	37241	38033	23338	33246	33000	18889
1966	8152	16580	12660	26500	37800	38840	23525	33700	33600	19900
1967	8340	16830	12975	27700	38625	39740	23690	34240	34300	20875
1968	8500	17049	13385	29225	39650	40590	23830	34840	35350	21800
1969	8628	17280	13795	30650	40800	41350	23950	35475	36850	22710
1970	8733	17520	14160	31975	42070	41949	24061	36120	38500	23609
1971	8796	17700	14500	33125	42800	42450	24171	36725	40100	24409
1972	8860	17900	14835	34175	43300	42820	24281	37200	41600	25207
1973	8927	18090	15110	35075	43700	43188	24391	37650	43050	25998
1974	8996	18275	15350	35875	43990	43498	24501	38075	44400	26725
1975	9063	18450	15565	36550	44250	43783	24611	38470	45650	27450
1976	9130	18620	15715	37100	44475	44058	24721	38860	46750	28135
1977	9194	18780	15860	37625	44650	44323	24831	39235	47750	28790
1978	9258	18940	16000	38125	44825	44568	24941	39605	48418	29410
1979	9319	19080	16140	38625	44980	44808	25051	39975	49000	30000
1980	9379	19222	16278	39102	45108	45008	25162	40344	49514	30578
1981	9442	19320	16375	39475	45225	45208	25280	40550	50000	31100
1982	9505	19440	16450	39825	45390	45383	25398	40700	50410	31590
1983	9568	19520	16520	40169	45600	45558	25516	40831	50820	32068
1984	9631	19600	16580	40504	45850	45733	25634	40952	51200	32500
SURFACE-TYPE GROUP J										
1964	2141	12899	3301	5572	19932	24168	5074	7920	418	2043
1965	2170	12980	3385	5897	20087	24368	5124	8133	442	2078
1966	2198	13160	3450	6137	20525	24763	5149	8390	463	2135
1967	2218	13370	3503	6327	21140	25175	5173	8710	484	2192
1968	2238	13620	3552	6497	21850	25600	5197	9097	503	2255
1969	2258	13780	3598	6647	22650	25999	5221	9490	521	2318
1970	2275	13957	3640	6772	23522	26349	5245	9823	535	2381
1971	2289	14070	3682	6897	23850	26525	5269	9978	546	2444
1972	2302	14240	3723	7022	24100	26665	5293	10098	557	2507
1973	2315	14360	3763	7130	24290	26800	5317	10198	567	2568
1974	2327	14490	3803	7230	24450	26925	5341	10285	576	2628
1975	2339	14600	3843	7330	24590	27040	5365	10362	584	2686
1976	2350	14700	3881	7430	24715	27150	5389	10437	592	2740
1977	2361	14800	3917	7515	24825	27260	5413	10510	599	2792
1978	2372	14880	3949	7600	24920	27360	5437	10575	606	2841
1979	2382	14950	3979	7675	25010	27456	5461	10637	612	2890
1980	2392	15047	4004	7748	25098	27546	5486	10697	618	2934
1981	2402	15100	4022	7820	25180	27626	5511	10732	623	2978
1982	2412	15160	4039	7880	25300	27706	5536	10765	628	3018
1983	2423	15225	4054	7940	25425	27781	5562	10795	632	3055
1984	2446	15275	4068	8000	25550	27856	5588	10820	636	3090

1/ Estimated on the basis of projections reported in Table II-19 of staff report, Study Number 1.

2/ Type F was phased out as retired and replaced by higher type flexible pavement. The original 1964 lane-miles were carried forward to avoid adjusting the computer program.

TABLE 16-2. -- PROJECTED LANE-MILES OF HIGHWAYS IN SERVICE DECEMBER 31, 1964 THROUGH 1984 BY CENSUS DIVISION AND SURFACE TYPE[1]

SYSTEM 4, FEDERAL-AID PRIMARY URBAN

YEAR	CENSUS DIVISION 1. NE	2. MA	3. SAN	4. SAS	5. ENC	6. WNC	7. ESC	8. WSC	9. M	10. P
	SURFACE-TYPE GROUP F[2]									
1964	125	175	83	336	35	247	194	222	52	83
1965	125	175	83	336	35	247	194	222	52	83
1966	125	175	83	336	35	247	194	222	52	83
1967	125	175	83	336	35	247	194	222	52	83
1968	125	175	83	336	35	247	194	222	52	83
1969	125	175	83	336	35	247	194	222	52	83
1970	125	175	83	336	35	247	194	222	52	83
1971	125	175	83	336	35	247	194	222	52	83
1972	125	175	83	336	35	247	194	222	52	83
1973	125	175	83	336	35	247	194	222	52	83
1974	125	175	83	336	35	247	194	222	52	83
1975	125	175	83	336	35	247	194	222	52	83
1976	125	175	83	336	35	247	194	222	52	83
1977	125	175	83	336	35	247	194	222	52	83
1978	125	175	83	336	35	247	194	222	52	83
1979	125	175	83	336	35	247	194	222	52	83
1980	125	175	83	336	35	247	194	222	52	83
1981	125	175	83	336	35	247	194	222	52	83
1982	125	175	83	336	35	247	194	222	52	83
1983	125	175	83	336	35	247	194	222	52	83
1984	125	175	83	336	35	247	194	222	52	83
	SURFACE-TYPE GROUP GO									
1964	3407	4440	1568	2699	6518	1971	2781	3630	1945	2211
1965	3440	4528	1614	2724	6760	2039	2865	3760	2060	2280
1966	3480	4580	1660	2749	6910	2063	2930	3850	2160	2348
1967	3520	4650	1706	2774	7010	2088	2975	3940	2230	2418
1968	3561	4710	1752	2809	7075	2113	3020	4000	2295	2520
1969	3617	4790	1798	2849	7110	2138	3032	4050	2350	2620
1970	3676	4860	1843	2891	7143	2163	3042	4100	2385	2715
1971	3728	4940	1885	2956	7165	2201	3065	4140	2420	2815
1972	3783	5015	1927	3026	7240	2239	3100	4180	2445	2912
1973	3844	5090	1969	3102	7340	2277	3140	4220	2460	3013
1974	3910	5168	2011	3178	7460	2315	3190	4270	2475	3118
1975	3979	5268	2053	3264	7590	2353	3245	4330	2495	3218
1976	4048	5360	2095	3355	7750	2391	3300	4418	2525	3320
1977	4117	5466	2138	3456	7915	2429	3360	4502	2565	3425
1978	4187	5568	2181	3557	8080	2468	3425	4590	2610	3530
1979	4257	5676	2224	3657	8265	2507	3490	4692	2665	3638
1980	4327	5786	2267	3757	8459	2546	3558	4790	2727	3740
1981	4410	5880	2313	3857	8615	2597	3618	4870	2788	3850
1982	4500	5992	2359	3957	8780	2649	3676	4960	2852	3950
1983	4590	6100	2405	4057	8960	2701	3736	5044	2918	4060
1984	4680	6218	2451	4157	9150	2753	3796	5138	2980	4163
	SURFACE-TYPE GROUP J									
1964	622	5606	944	746	4230	3175	686	2060	143	1558
1965	640	5678	946	768	4381	3278	710	2120	153	1708
1966	652	5751	953	791	4475	3365	725	2160	160	1800
1967	660	5838	964	814	4540	3451	738	2180	165	1860
1968	667	5925	977	837	4565	3516	749	2200	169	1900
1969	672	6028	990	860	4585	3558	753	2230	173	1935
1970	678	6138	1004	883	4595	3596	758	2250	176	1950
1971	684	6239	1018	906	4650	3646	763	2280	178	1960
1972	692	6350	1038	929	4715	3696	771	2300	180	1970
1973	700	6471	1058	953	4785	3746	782	2320	182	1990
1974	709	6580	1078	977	4855	3796	794	2340	183	2025
1975	718	6701	1100	1001	4940	3846	807	2360	184	2060
1976	728	6832	1123	1025	5030	3898	821	2380	185	2100
1977	738	6952	1148	1049	5125	3950	835	2430	187	2150
1978	748	7080	1173	1073	5225	4015	849	2480	189	2200
1979	758	7210	1198	1097	5330	4090	863	2533	191	2250
1980	770	7339	1225	1121	5438	4167	877	2582	193	2311
1981	784	7480	1252	1147	5530	4244	891	2638	196	2360
1982	798	7621	1277	1173	5640	4321	905	2680	198	2422
1983	813	7763	1302	1199	5750	4398	919	2722	202	2493
1984	828	7905	1327	1226	5865	4475	933	2778	206	2558

1/ Estimated on the basis of projections reported in Table II-19 of staff report, Study Number 1.

2/ Type F was phased out as retired and replaced by higher type flexible pavement. The original 1964 lane-miles were carried forward to avoid adjusting the computer program.

5. TOTAL CONSTRUCTION EXPENDITURES YEARLY FROM 1965 THROUGH 1984

One additional input to the computer was required for estimating the total highway construction expenditures from 1965 through 1984: the costs per lane-mile of new construction, reconstruction, and resurfacing. The computer also required instructions on how to compute for each of the 20 years the number of lane-miles of new construction, reconstruction, and resurfacing. These three basic factors were determined next for each of the four highway systems and for each surface type.

A. Base Construction Cost

The base highway construction costs are given in Chapter 8. Tables 8-9, 8-10, and 8-11 were used for the base costs for the study of financial requirements from 1965 to 1984.

B. Construction Cost of New Highways

New construction cost for each system for 1965 to 1984 is restricted to the yearly increase in lane-miles as indicated by the control lane-miles. Price factors for new construction that are applicable to the Interstate systems are not the same throughout the 20-year project period. After 1972 all new construction was priced at a lower cost than those lane-miles projected from 1965 through 1972.

All Interstate-system new construction costs for the projected years through 1972, were obtained from table 8-10

(Chapter 8) and were divided by four (reducing four lanes to lane-miles) to give the cost per lane-mile at the base axle-weight limit. The costs of new construction per lane-mile for the projected period from 1973 through 1984 were obtained in the same manner as those for 1965 through 1972 but include only pavement costs from table 8-9. It was assumed that the Interstate system will be completed during 1972 and that the increased system lane-mileage for each year thereafter will result from increased traffic lanes, not from increased system centerline length.

New construction costs by surface type on the Federal-aid primary system were treated in much the same manner as Interstate-system costs were, but with one factor applied throughout the projected (1965 to 1984) period, and a factor of two instead of four used to produce lane-mile cost. The reduced lane mileage factor was required, since the existing Federal-aid primary system averages approximately 2 lanes per mile. See tables 16-3 and 16-4 for the cost per lane-mile of new construction on the Interstate system and table 16-6 for the cost for the Federal-aid primary system.

C. Reconstruction Cost

For flexible and rigid pavements on Interstate systems 1 and 2, a "ratio" of National reconstruction cost per centerline mile was devised by comparing the Nationwide reconstruction

Tables 16-3 - 16-6. -- National average cost of new construction and reconstruction on the Interstate and Federal-aid primary system, expressed in thousands of dollars per lane-mile

The increment of cost above the base axle-weight limit is from analysis Method 1-M.

System	Rigid pavement					Flexible pavement				
	Single/tandem maximum axle-weight limits, kips					Single/tandem maximum axle-weight limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
Table 16-3										
Interstate system: Cost of new construction through 1972										
1. Interstate, Rural	1,007	1,440	1,981	2,005	2,027	952	1,367	1,899	1,914	1,929
2. Interstate, Urban	4,047	5,647	8,099	8,116	8,130	3,988	5,571	8,016	8,029	8,043
Table 16-4										
Interstate system: Cost of new construction (adding lanes only) after 1972										
1. Interstate, Rural	306	421	541	547	552	244	344	456	463	468
2. Interstate, Urban	313	427	547	552	556	253	350	462	465	468
Table 16-5										
Interstate system: Cost of reconstruction										
1. Interstate, Rural	495	697	958	969	980	462	657	913	920	927
2. Interstate, Urban	1,930	2,678	3,837	3,844	3,851	1,893	2,631	3,784	3,790	3,796
Table 16-6										
Federal-aid primary system: Cost of new construction and reconstruction										
3. Federal-aid Primary, Rural	795	1,209	1,733	1,739	1,744	720	1,103	1,612	1,621	1,630
4. Federal-aid Primary, Urban	1,409	2,148	3,146	3,159	3,169	1,333	2,042	3,025	3,039	3,052

cost furnished by the Office of Engineering with the corresponding cost taken from table 8-10. This step was necessary owing to the differences in the cost estimates of these two reports. Since the cost of reconstruction contains little right-of-way activity, 90 percent of the right-of-way cost was excluded from the costs taken from table 8-10. The end product of this first step was then applied to the total system costs found in table 8-10, resulting in total system costs per centerline-mile for each individual census division.

The reconstruction price factors for all systems, surface types, and axle-weight groups that are outlined in this section of the report apply equally to all projected years of the study. See table 16-5 for the lane-mile cost of reconstruction on the Interstate System. The comparable costs for the Federal-aid primary systems are given in table 16-6.

These increments of construction cost for the higher axle-weight limits were added to the base costs to arrive at the results given in tables 16-3 to 16-6. The added construction costs include the costs of small drainage and earthwork, pavement structure, shoulders, and bridges.

6. SPLIT OF TOTAL YEARLY CONSTRUCTION INTO NEW CONSTRUCTION, RECONSTRUCTION, AND RESURFACING

A somewhat arbitrary scheme, but realistic in concept, was used to determine separately the amounts of new construction, reconstruction, and resurfacing for each year from 1965 to 1985. The scheme is based primarily on past construction years.

New construction on the four highway systems from 1965 to 1985 was determined to be the yearly increase in the control lane mileage. Reconstruction and resurfacing combined is equal to the total mileage retired each year. The method used to divide the total retirements (replacements) into reconstruction and resurfacing was based on the age of the retirements (year built) and the surface type.

The Federal-Aid Highway Act of 1956 established a bench mark year in design standards. Although the standards are particularly applicable to the Interstate system, they also have increased the importance of long-range traffic requirements for newly designed primary mileage. The year 1957, when the new design criteria took effect, was selected as the transition year for all four highway systems. For Systems 3 and 4, Federal-aid primary rural and urban, an additional transition year, 1946, was used in order to take into account the differences in design and construction before and during the World War II years.

On Systems 1 and 2, Interstate rural and urban, all retirements of all surface types constructed before 1958 are classed as reconstruction. All retired lane-miles from construction vintages of 1958 and later are classed as resurfacing. The percentage breakdown between reconstruction and resurfacing for the Federal-aid primary rural and urban systems varies for each surface-type group as follows:

Surface type	Vintages of 1946 and earlier		Vintages of 1947-1957		Vintages of 1958-1984	
	Recon-struction	Resur-facing	Recon-struc-tion	Resur-facing	Recon-struc-tion	Resur-facing
Group F	100	0	90	10	10	90
Group GO	90	10	60	40	0	100
Group J	85	15	50	50	0	100

7. SELECTION OF SERVICE LIVES AND SURVIVOR CURVES FOR INCREASED AXLE-WEIGHT LIMITS

One of the concepts of this analysis is that, under higher axle-weight limits for the period of 1965 to 1985, the pavements constructed before 1965 would reach a state of physical wear warranting reconstruction or resurfacing some years sooner than they would without the increase in axle-weight limits. For all vintages before 1965, the average service life was adjusted for each axle-weight level above the base condition by the ratio of the E 18-kip axle application at the base condition to the E 18-kip axle application at each increased level of axle-weight limits. These reduced service lives are given in table 16-1. Because the pavement design is a function of the total E 18-kip axle applications over a specific period, it is reasonable to adjust this specific period of time used in design proportionally to any change in the total E 18-kip axle applications.

For all vintages 1965 to 1985, no adjustment in service lives is required. The analysis method provides for determining separately the 20-year capital outlays for each axle-weight level. Therefore, all construction, reconstruction, and resurfacing within the 20-year period reflected pavement designs for a particular axle-weight limit. The final comparison, then, was between levels of capital outlay required from one axle-weight limit to another. The effects of increased axle-weight levels show up in the increased construction cost of the complete highway.

The pavements from 1965 to 1985 with 20-year service lives are perhaps of higher structural quality than are many of the older pavements existing on the highway systems. It would follow, then, that some of the existing pavements would perhaps experience a greater shortening of service life than that given in table 16-1. But no adjustments were made to correct for any possible error in this procedure, because no easily applied method of doing so was conceived. Not knowing the structural quality of existing pavements of their present serviceability index (PSI) precluded making any adjustments on the basis of these factors.

8. COMPUTER CALCULATIONS AND PRINT-OUTS

The main computer print-out is table 16-8 (for East North Central census division only) showing the total dollars of capital outlay for each highway system, census division, and axle-weight level for each year from 1965 through 1984.

The minus differences on the lefthand side of table 16-8 occur when the more rapid retirements in the early years at the increased axle-weight levels bring about greater construction activities during the early part of the projected period and lesser amounts in the later years than would have been the case had the present pavement design and resulting retirement rates prevailed. These pavements that are retired more rapidly in the early years with increasing levels of axle-weight limit are replaced with 20-year pavement of a high type designed for the specific axle-weight limit--pavement having a much slower rate of retirement than that of earlier vintages. Thus, under the higher axle-weight limits, replacement construction is speeded up in the early years and then slowed down in the middle and later years, as compared to the replacement schedule under the base condition.

The yearly totals of capital outlay from 1965 through 1984 in table 16-8 are summed to get the 20-year totals shown on the left-hand side of table 16-9. On the right-hand side of table 16-9 are shown the 20-year totals of the present worth at 6 percent of each of the yearly capital outlays. These present

TABLE 16-8. -- ADDITIONAL CONSTRUCTION COST AND TOTAL CAPITAL OUTLAYS FOR HIGHWAYS, 1965 THROUGH 1984, BY AXLE-WEIGHT LIMITS *1

SYSTEM 1 INTERSTATE RURAL

CENSUS DIVISION 5 EAST NORTH CENTRAL

YEAR	ADDED CONSTRUCTION COST *2 - DOLLARS FROM THE BASE SINGLE/TANDEM AXLE WEIGHT LIMITS *3				TOTAL CAPITAL OUTLAYS - DOLLARS				
	INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				
	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
1965	3388334	6741108	10250441	13628975	275914236	279302570	282655344	286164677	289543211
1966	3755339	7464823	11482746	15452790	258313507	262068846	265778330	269796253	273766297
1967	3905025	8372491	13024251	17445564	249492108	253397133	257864599	262516359	266937672
1968	4392046	8677773	13226115	17795745	235903653	240295699	244581426	249129768	253699398
1969	4253672	8821823	13399990	17486949	232027000	236280672	240848823	245426990	249513949
1970	4462094	8704187	12565081	17587580	232956394	237418488	241660581	245521475	250543974
1971	4209518	8173063	14524223	22254756	233661483	237871001	241834546	248185706	255916239
1972	3993836	10996746	18315008	24821431	231246417	235240253	242243163	249561425	256067848
1973	6041730	13052080	18567164	19058461	82951957	88993687	96004037	101519121	102010418
1974	7251954	13131383	13221294	11628588	84982036	92233990	98113419	98203330	96610624
1975	6607797	7641603	6473732	5523241	87708752	94316549	95350355	94182484	93231993
1976	2466123	1021190	-994002	-2539646	39620528	42086651	40641718	38626526	37080882
1977	-824458	-3190332	-4071882	-8058802	40728320	39903862	37537988	36656438	32669518
1978	-1912255	-2931827	-5701023	-10150675	39473927	37561672	36542100	33772904	29323252
1979	-2193475	-3438315	-7470444	-11546568	38364703	36171228	34926388	30894259	26818135
1980	-1079828	-4120225	-8174159	-11472006	36877509	35797681	32757284	28703350	25405503
1981	-940268	-4448179	-8331700	-10468508	35649396	34709128	31201217	27317696	25180888
1982	-2312361	-6069363	-9046454	-9844639	35798071	33485710	29728708	26751617	25953432
1983	-3146035	-6674447	-8591156	-8329644	35652511	32506476	28978064	27061355	27322867
1984	-3276867	-6337581	-7117298	-6414245	35196244	31919377	28858663	28078946	28781999

*1 BASED UPON ADDITIONAL HIGHWAY CONSTRUCTION COST INCURRED WITH EACH PROJECTED INCREASE IN AXLE WEIGHT LIMITS. CAPITAL OUTLAY COST FOR THE BASE AXLE WEIGHT LIMITS ARE ESTIMATED FROM A FORECAST OF THE LANE-MILES WHICH WILL BE REQUIRED TO BE CONSTRUCTED,RECONSTRUCTED OR RESURFACED EACH YEAR.

*2 INCLUDES- PAVEMENT, SHOULDERS, EARTHWORK, DRAINAGE AND BRIDGE COSTS.

*3 BASE AXLE WEIGHT LIMITS ARE- 22/38 FOR NE & MA , 20/35 FOR SAN & SAS , ALL OTHER CENSUS DIVISION ARE 18/32.

TABLE 16-8. -- ADDITIONAL CONSTRUCTION COST AND TOTAL CAPITAL OUTLAYS FOR HIGHWAYS, 1965 THROUGH 1984, BY AXLE-WEIGHT LIMITS *1

SYSTEM 2 INTERSTATE URBAN

CENSUS DIVISION 5 EAST NORTH CENTRAL

YEAR	ADDED CONSTRUCTION COST *2 - DOLLARS FROM THE BASE SINGLE/TANDEM AXLE WEIGHT LIMITS *3 — INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				TOTAL CAPITAL OUTLAYS - DOLLARS — INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				
	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
1965	1519128	2977366	4443372	5983474	273405521	274924649	276382887	277848893	279388995
1966	2196347	4064894	6005039	8047657	358120747	360317094	362185641	364125786	366168404
1967	1799260	4150178	6640940	9234312	417404374	419203634	421554552	424045314	426638686
1968	2600418	5635598	8410798	11261539	460040488	462640906	465676086	468451286	471302027
1969	2767462	5290391	7806344	10056495	493439551	496207013	498729942	501245895	503496046
1970	2258284	4207815	5852465	7042849	507726714	509984998	511934529	513579179	514769563
1971	1490336	2343516	3700932	5995264	538782488	540272824	541126004	542483420	544777752
1972	1341650	3460489	8528459	12475367	557512802	558854452	560973291	566041261	569988169
1973	3069154	7380242	11348026	15644210	40326719	43395873	47706961	51674745	55970929
1974	3998646	7353298	12476197	11747601	42926363	46925009	50279661	55402560	54673964
1975	4107853	7779339	4520091	-123961	45124627	49232480	52903966	49644718	45000666
1976	2653387	-1282872	-6874564	-12079605	36383684	39037071	35100812	29509120	24304079
1977	-3785944	-8719240	-14802611	-18027334	36751466	32965522	28032226	21948855	18724132
1978	-4728513	-10012395	-12846005	-14220029	31666204	26937691	21653809	18820199	17446175
1979	-5802423	-8849678	-10331466	-10931625	27166768	21364345	18317090	16835302	16235143
1980	-3655935	-4560021	-5743991	-5879148	22069989	18414054	17509968	16325998	16190841
1981	-1377307	-2705573	-2836480	-2955331	19199679	17822372	16494106	16363199	16244348
1982	-1349032	-1400020	-1532536	-1703142	17993672	16644640	16593652	16461136	16290530
1983	-469626	-573482	-745783	-628987	17338113	16868487	16764631	16592330	16709126
1984	-97819	-200321	-8886	-621397	17144987	17047168	16944666	17136101	16523590

*1 BASED UPON ADDITIONAL HIGHWAY CONSTRUCTION COST INCURRED WITH EACH PROJECTED INCREASE IN AXLE WEIGHT LIMITS. CAPITAL OUTLAY COST FOR THE BASE AXLE WEIGHT LIMITS ARE ESTIMATED FROM A FORECAST OF THE LANE-MILES WHICH WILL BE REQUIRED TO BE CONSTRUCTED,RECONSTRUCTED OR RESURFACED EACH YEAR.

*2 INCLUDES- PAVEMENT, SHOULDERS, EARTHWORK, DRAINAGE AND BRIDGE COSTS.

*3 BASE AXLE WEIGHT LIMITS ARE- 22/38 FOR NE & MA , 20/35 FOR SAN & SAS , ALL OTHER CENSUS DIVISION ARE 18/32.

TABLE 16-8. -- ADDITIONAL CONSTRUCTION COST AND TOTAL CAPITAL OUTLAYS FOR HIGHWAYS, 1965 THROUGH 1984, BY AXLE-WEIGHT LIMITS *1

SYSTEM 3 FEDERAL-AID PRIMARY RURAL

CENSUS DIVISION 5 EAST NORTH CENTRAL

YEAR	ADDED CONSTRUCTION COST *2 - DOLLARS FROM THE BASE SINGLE/TANDEM AXLE WEIGHT LIMITS *3				TOTAL CAPITAL OUTLAYS - DOLLARS				
	INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				
	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
1965	49345896	101677180	156769343	209647421	522378277	571724173	624055457	679147620	732025698
1966	41139952	82712171	124927307	163719049	631109209	672249161	713821380	756036516	794828258
1967	32377218	63547148	94349844	122175055	686494354	718871572	750041502	780844198	808669409
1968	25542893	51241343	77256899	99181728	711925592	737468485	763166935	789182491	811107320
1969	23234482	44178262	62084031	73837160	726792120	750026602	770970382	788876151	800629280
1970	17528727	31608075	39824037	38665024	742412983	759941710	774021058	782237020	781078007
1971	11223767	14477490	9012457	-1593076	505258836	516482603	519736326	514271293	503665760
1972	1769518	-4149018	-17064966	-25854391	422951693	424721211	418802675	405886727	397097302
1973	-6221235	-18324619	-27616661	-31666939	365844736	359623501	347520117	338228075	334177797
1974	-11332059	-21301721	-23947400	-32458973	310357075	299025016	289055354	286409675	277898102
1975	-10168594	-14177125	-25178026	-38770402	275769690	265601096	261592565	250591664	236999288
1976	-6235327	-13532326	-27212356	-46363071	242839715	236604388	229307389	215627359	196476644
1977	-6164020	-17969560	-35638810	-51931263	211401666	205237646	193432106	175762856	159470403
1978	-9412966	-25001634	-44084355	-53820744	193117473	183704507	168115839	149033118	139296729
1979	-11989356	-29528987	-43610028	-49912203	171916177	159926821	142387190	128306149	122003974
1980	-14587913	-32047896	-41024811	-46206297	152015994	137428081	119968098	110991183	105809697
1981	-16530456	-29980672	-36416662	-39954908	134789320	118258864	104908648	98372658	94834412
1982	-16354636	-25050053	-30627372	-32222746	138420422	122065786	113370369	107793050	106197676
1983	-13870520	-19742993	-22577577	-23672161	135948872	122078352	116205879	113371295	112276711
1984	-8804040	-13391279	-14781902	-14758245	133157152	124353112	119765873	118375250	118398907

*1 BASED UPON ADDITIONAL HIGHWAY CONSTRUCTION COST INCURRED WITH EACH PROJECTED INCREASE IN AXLE WEIGHT LIMITS. CAPITAL OUTLAY COST FOR THE BASE AXLE WEIGHT LIMITS ARE ESTIMATED FROM A FORECAST OF THE LANE-MILES WHICH WILL BE REQUIRED TO BE CONSTRUCTED,RECONSTRUCTED OR RESURFACED EACH YEAR.

*2 INCLUDES- PAVEMENT, SHOULDERS, EARTHWORK, DRAINAGE AND BRIDGE COSTS.

*3 BASE AXLE WEIGHT LIMITS ARE- 22/38 FOR NE & MA , 20/35 FOR SAN & SAS , ALL OTHER CENSUS DIVISION ARE 18/32.

TABLE 16.8. -- ADDITIONAL CONSTRUCTION COST AND TOTAL CAPITAL OUTLAYS FOR HIGHWAYS, 1965 THROUGH 1984, BY AXLE-WEIGHT LIMITS *1

SYSTEM 4 FEDERAL-AID PRIMARY URBAN

CENSUS DIVISION 5 EAST NORTH CENTRAL

YEAR	ADDED CONSTRUCTION COST *2 - DOLLARS FROM THE BASE SINGLE/TANDEM AXLE WEIGHT LIMITS *3				TOTAL CAPITAL OUTLAYS - DOLLARS				
	INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				INCREASED SINGLE/TANDEM AXLE WEIGHT LIMITS,KIPS				
	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
1965	13269389	26656794	40239303	52829558	266634247	279903636	293291041	306873550	319463805
1966	10440570	21138599	31692669	42181170	197774316	208214886	218912915	229466985	239955486
1967	9250490	18356308	27781682	36752938	161310685	170561175	179666993	189092367	198063623
1968	8426320	18052000	27104762	34831393	127032950	135459270	145084950	154137712	161864343
1969	8719607	16570915	22043430	25016935	110713114	119432721	127284029	132756544	135730049
1970	6538504	10643737	10730916	9620398	104557452	111095956	115201189	115288368	114177850
1971	3344005	1675621	933827	-166797	114345296	117689301	116020917	115279123	114178499
1972	-1561282	-1573825	-2846386	-5459411	131961173	130399891	130387348	129114787	126501762
1973	-405376	-1561438	-4268903	-7906819	134872024	134466648	133310586	130603121	126965205
1974	-566814	-2879350	-6230238	-12204841	136242300	135675486	133362950	130012062	124037459
1975	-1457471	-5273599	-10922049	-17037090	140693751	139226280	135420152	129771702	123656661
1976	-2144395	-6994737	-14225674	-18170654	148563728	146419333	141568991	134338054	130393074
1977	-4630313	-11538454	-16616805	-18465190	147385086	142754773	135846632	130768281	128919896
1978	-5429157	-12557674	-15128106	-16146080	142651636	137222479	130093962	127523530	126505556
1979	-6764754	-11287645	-13024417	-13666931	145936948	139172194	134649303	132912531	132270017
1980	-6368557	-9184858	-10428221	-11182236	144261296	137892739	135076438	133833075	133079060
1981	-5531238	-6968691	-8415417	-9511750	117920342	112389104	110951651	109504925	108408592
1982	-3749545	-5722635	-6234591	-6450402	123004441	119254896	117281806	116769850	116554039
1983	-1732825	-2484575	-3004746	-3244391	123484091	121751266	120999516	120479345	120239700
1984	-1591321	-2095189	-2130343	-1739599	127056683	125465362	124961494	124926340	125317084

*1 BASED UPON ADDITIONAL HIGHWAY CONSTRUCTION COST INCURRED WITH EACH PROJECTED INCREASE IN AXLE WEIGHT LIMITS. CAPITAL OUTLAY COST FOR THE BASE AXLE WEIGHT LIMITS ARE ESTIMATED FROM A FORECAST OF THE LANE-MILES WHICH WILL BE REQUIRED TO BE CONSTRUCTED,RECONSTRUCTED OR RESURFACED EACH YEAR.

*2 INCLUDES- PAVEMENT, SHOULDERS, EARTHWORK, DRAINAGE AND BRIDGE COSTS.

*3 BASE AXLE WEIGHT LIMITS ARE- 22/38 FOR NE & MA , 20/35 FOR SAN & SAS , ALL OTHER CENSUS DIVISION ARE 18/32.

TABLE 16-9. -- TWENTY-YEAR CAPITAL OUTLAYS AND PRESENT WORTH VALUES FOR HIGHWAYS, 1965 THROUGH 1984, BY AXLE-WEIGHT LIMITS AND CENSUS DIVISION *1

Sheet 1 of 2

IN DOLLARS

CENSUS DIVISION	20-YEAR CAPITAL OUTLAYS SINGLE/TANDEM AXLE WEIGHT LIMITS, KIPS					PRESENT WORTH AT 6% OF 20-YEAR CAPITAL OUTLAYS SINGLE/TANDEM AXLE WEIGHT LIMITS, KIPS				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
SYSTEM 1. INTERSTATE RURAL										
1. NE			734171762	740730587	746541676			529060363	534119002	538881381
2. MA			1665307265	1727805582	1778984893			1189308872	1237621847	1278775511
3. SAN		1483847010	1502478237	1517615990	1529832977		1095852065	1110622662	1123444880	1134304543
4. SAS		1487946590	1498787835	1508796229	1517743124		1048528975	1056079139	1063462584	1070425973
5. ENC	2542518752	2581560673	2608106753	2628070679	2646378099	1802689304	1834153796	1860440711	1883213695	1903612998
6. WNC	2131493849	2152085120	2170286424	2186653370	2201397517	1456420141	1472034921	1486666823	1500504595	1513782695
7. ESC	1654422210	1681366001	1705258656	1725967535	1744231719	1180835053	1201705819	1220761081	1238056494	1253533880
8. WSC	2135927188	2182762348	2216692049	2240710025	2261301367	1479282872	1513706802	1542244914	1565786798	1585864862
9. M	2527776847	2539678582	2551318133	2562526163	2573657664	1796754998	1805397735	1814006538	1822563272	1831341497
10. P	1978354193	2010903133	2037726995	2060134782	2079785028	1402562247	1427147925	1448861796	1468151802	1485521136
SYSTEM 2. INTERSTATE URBAN										
1. NE			1479805809	1483269682	1485519895			1124806800	1128453734	1131366577
2. MA			3565865914	3575085772	3583271415			2680121173	2692817755	2704502616
3. SAN		1980873562	1986900843	1992416780	1997520814		1506823942	1511957972	1516777865	1521309924
4. SAS		501200540	502804963	504262226	505580248		356319675	358014813	359659297	361260831
5. ENC	3960524956	3969060282	3976864480	3984535297	3990843165	2891739398	2902826207	2912947375	2922899779	2931552298
6. WNC	940599868	943738827	946663787	949432380	952175268	693187926	696223383	699169657	702123011	704968082
7. ESC	959865863	963806848	967008573	970024124	972721398	685382865	689052701	692385491	695617340	698535123
8. WSC	1670933394	1680350663	1689216164	1696742709	1703352816	1231307125	1238427369	1245373347	1251809510	1257800013
9. M	573652810	575593579	577419248	578792737	580252841	428305419	429774988	431182763	432457547	433712136
10. P	3301583659	3320964313	3337893450	3351522999	3360582593	2478820314	2493958313	2508258930	2521329380	2532344552

*1 INCLUDES PAVEMENT, SHOULDERS, EARTHWORK, DRAINAGE AND BRIDGE COSTS INCURRED WITH EACH PROJECTED INCREASE IN AXLE WEIGHT LIMITS. CAPITAL OUTLAY COST FOR THE BASE AXLE WEIGHT LIMITS ARE ESTIMATED FROM A FORECAST OF THE LANE-MILES WHICH WILL BE REQUIRED TO BE CONSTRUCTED, RECONSTRUCTED OR RESURFACED EACH YEAR.

TABLE 16-9. -- TWENTY-YEAR CAPITAL OUTLAYS AND PRESENT WORTH VALUES FOR HIGHWAYS, 1965 THROUGH 1984, BY AXLE-WEIGHT LIMITS AND CENSUS DIVISION *1

Sheet 2 of 2

IN DOLLARS

CENSUS DIVISION	20-YEAR CAPITAL OUTLAYS — SINGLE/TANDEM AXLE WEIGHT LIMITS, KIPS					PRESENT WORTH AT 6% OF 20-YEAR CAPITAL OUTLAYS — SINGLE/TANDEM AXLE WEIGHT LIMITS, KIPS				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
SYSTEM 3. FEDERAL-AID PRIMARY RURAL										
1. NE			1991603582	2002580049	2012881335			1360173867	1377711718	1395269402
2. MA			5271013120	5310498787	5344305323			3563544622	3626199270	3684858493
3. SAN		2493485789	2525735800	2551450993	2574176577		1716665308	1766438286	1807912965	1842936461
4. SAS		4636282175	4651223691	4664991408	4678912742		3145290908	3159839176	3174169864	3188106777
5. ENC	7414901356	7485392687	7540245142	7589344348	7632941374	5019571919	5132987651	5233442742	5325434807	5403301667
6. WNC	4555768551	4581120534	4606646035	4630707779	4653430466	3093119744	3119568940	3147095275	3174287451	3200244692
7. ESC	1558900403	1580126977	1599863763	1563261043	1577281532	1101477392	1131681745	1164804986	1150251234	1171654321
8. WSC	2774883256	2809735308	2836476066	2860555651	2886901642	1884550481	1934069383	1977573836	2017130718	2065485927
9. M	2697794819	2701943522	2706711020	2711139823	2716067391	1768265505	1772472313	1777201614	1782026580	1786978466
10. P	3811348927	3845586407	3876694081	3906230807	3933672696	2502549332	2543218549	2580057744	2614880361	2646524000
SYSTEM 4. FEDERAL-AID PRIMARY URBAN										
1. NE			1281209389	1287466615	1293745224			776051458	784049540	791852134
2. MA			4119003768	4140886047	4159166663			2538428360	2571850593	2601825156
3. SAN		836233939	842470795	848023907	853090004		511380870	520375229	528650356	536013309
4. SAS		858729781	861022122	863304889	865550888		502392648	504551076	506723488	508950880
5. ENC	2846401559	2864447396	2879372663	2893452252	2906281760	1699949119	1731836700	1759491578	1783967559	1804907013
6. WNC	593120469	597051135	600521938	603669344	606481390	359115966	363195397	367007444	370710400	374169473
7. ESC	353530571	357799778	360957730	363833069	366396569	222646915	228214660	232710306	236692924	240076019
8. WSC	556748603	562295032	566510826	570370417	573957965	335860176	342267226	347862777	352765068	357137430
9. M	218231195	219360886	220193318	220855076	221419998	137499153	138883043	139950305	140902270	141750852
10. P	1492517465	1506431739	1519415494	1531785989	1543467902	911471877	925832915	938613272	950635017	961542504

*1 INCLUDES PAVEMENT, SHOULDERS, EARTHWORK, DRAINAGE AND BRIDGE COSTS INCURRED WITH EACH PROJECTED INCREASE IN AXLE WEIGHT LIMITS. CAPITAL OUTLAY COST FOR THE BASE AXLE WEIGHT LIMITS ARE ESTIMATED FROM A FORECAST OF THE LANE-MILES WHICH WILL BE REQUIRED TO BE CONSTRUCTED, RECONSTRUCTED OR RESURFACED EACH YEAR.

worth totals afford a better comparison of the effects of axle-weight limits, because they are expressed in terms of an equivalent common year: 1965.

Tables 16-10 and 16-11 for the East North Central census division give the dollar capital outlays year by year separately for new construction, reconstruction, and resurfacing. It may be noted from table 16-11 that over the 20-year period the dollars of capital outlay shift from reconstruction in the early years to resurfacing in the later years.

9. DISCUSSION OF RESULTS-- 20-YEAR FINANCIAL REQUIREMENTS

Construction costs at the five levels of axle-weight limits were given in table 16-8 for the East North Central census division and for the rural and urban Interstate and primary highway systems.

A. Interstate Systems 1 and 2

From table 16-8, it may be observed that the annual construction outlays for the Interstate rural system at all axle-weight limits are highest for the year 1965 and that they decrease to 1972, when they suddenly fall to a much lower figure. The construction program on Interstate rural and urban systems was set to provide for completion of the system by the end of 1972. After 1972 the construction on the Interstate system is only that necessary for adding some additional lanes and for resurfacing retired mileages of prior vintages.

Figures 16-4 and 5 for the Interstate rural system in census division 5, East North Central, show the total capital outlays from 1965 to 1985 as a percentage of what they are

Table 16-10. -- Cost of new construction, reconstruction, and resurfacing, 1965 to 1984, on the Interstate system, East North Central census division, for five levels of axle-weight limits.

(thousand dollars)

Sheet 1 of 3

Year	System 1. Interstate rural					System 2. Interstate urban				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	New construction costs									
1965	269,269	271,056	272,768	274,418	275,975	261,629	261,955	262,276	262,592	262,898
1966	250,464	252,132	253,729	255,268	256,719	344,934	345,364	345,783	346,204	346,608
1967	240,244	241,848	243,382	244,860	246,253	402,234	402,736	403,230	403,716	404,187
1968	225,111	226,620	228,062	229,451	230,759	443,380	443,934	444,479	445,016	445,535
1969	220,001	221,478	222,889	224,247	225,526	474,756	475,349	475,932	476,507	477,062
1970	220,001	221,478	222,889	224,247	225,526	488,115	488,726	489,326	489,918	490,490
1971	220,001	221,478	222,889	224,247	225,526	519,491	520,141	520,780	521,409	522,017
1972	217,140	218,598	219,991	221,333	222,596	540,037	540,713	541,377	542,032	542,665
1973	68,564	69,571	70,507	71,384	72,174	24,065	24,263	24,454	24,637	24,805
1974	68,556	69,564	70,501	71,378	17,168	24,003	24,201	24,391	24,574	24,742
1975	68,620	69,628	70,564	71,442	72,232	24,120	24,319	24,510	24,694	24,862
1976	18,032	13,297	18,543	18,774	18,982	12,701	12,806	12,906	13,003	13,092
1977	18,039	18,304	18,549	18,780	18,987	12,701	12,806	12,906	13,003	13,092
1978	18,032	18,297	18,543	18,774	18,982	12,763	12,868	12,969	13,066	13,156
1979	18,032	18,297	18,543	18,774	18,982	12,701	12,806	12,906	13,003	13,092
1980	18,039	18,304	18,549	18,780	18,987	12,701	12,806	12,906	13,003	13,092
1981	18,032	18,297	18,543	18,774	18,982	12,708	12,812	12,913	13,010	13,099
1982	18,032	18,297	18,543	18,774	18,982	12,701	12,806	12,906	13,003	13,092
1983	18,039	18,304	18,549	18,780	18,987	12,708	12,812	12,913	13,010	13,099
1984	18,032	18,297	18,543	18,774	18,982	12,701	12,806	12,906	13,003	13,092

Table 16-10. -- Cost of new construction, reconstruction, and resurfacing, 1964 to 1984, on the Interstate system, East North Central census division, for five levels of axle-weight limits.

(thousand dollars)

Sheet 2 of 3

Year	System 1. Interstate rural					System 2. Interstate urban				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Reconstruction costs									
1965	6,645	8,246	9,886	11,744	13,565	11,765	12,956	14,093	15,241	16,474
1966	7,847	9,929	12,038	14,506	17,009	13,172	14,936	16,380	17,901	19,538
1967	9,239	11,530	14,438	17,564	20,533	15,153	16,447	18,302	20,303	22,421
1968	10,772	13,718	16,385	19,440	22,432	16,639	18,682	21,168	23,398	25,728
1969	11,974	14,662	17,633	20,494	22,731	18,657	20,825	22,758	24,689	26,367
1970	12,820	15,584	17,981	19,686	22,146	19,576	21,210	22,529	23,554	24,117
1971	13,304	15,520	17,167	20,659	24,876	19,221	20,025	20,191	20,827	22,415
1972	13,320	14,979	19,052	22,631	24,368	17,326	17,916	19,277	23,547	26,713
1973	12,867	16,500	20,257	21,402	16,781	15,966	18,721	22,704	26,304	30,240
1974	13,877	18,102	19,772	14,762	8,224	18,425	22,072	25,064	29,771	28,635
1975	15,210	18,008	14,134	7,891	3,671	20,254	23,973	27,242	23,517	18,434
1976	16,068	14,7[illegible]	8,855	3,671	1,665	22,633	24,953	20,666	14,675	9,140
1977	15,274	10,2[illegible]	4,018	1,891	118	22,653	18,496	13,200	6,755	3,270
1978	11,983	5,844	2,454	570	--	17,111	12,000	6,385	3,271	1,777
1979	8,858	3,094	1,137	113	--	12,254	6,098	2,779	1,163	518
1980	5,481	2,083	306	--	--	6,740	2,791	1,728	486	456
1981	2,815	918	292	--	--	3,462	1,880	461	433	390
1982	1,987	331	--	--	--	1,896	438	417	376	319
1983	1,220	175	--	--	--	910	401	370	317	494
1984	568	235	--	--	--	389	362	320	594	--

Table 16-10. -- Cost of new construction, reconstruction, and resurfacing, 1965 to 1984, on the Interstate system, East North Central census division, for five levels of axle-weight limits.

(thousand dollars)

Sheet 3 of 3

Year	System 1. Interstate rural					System 2. Interstate urban				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Resurfacing costs									
1965	1	1	2	3	4	12	13	14	15	17
1966	2	7	11	23	38	14	16	18	20	23
1967	8	19	44	92	152	18	21	23	26	31
1968	20	57	135	239	459	21	25	29	37	39
1969	52	141	327	686	1,257	26	33	39	50	67
1970	135	356	791	1,589	2,872	36	50	79	108	163
1971	356	873	1,779	3,280	5,514	70	107	156	248	346
1972	787	1,663	3,199	5,598	9,105	150	226	319	462	610
1973	1,521	2,923	5,240	8,733	13,056	296	412	548	734	926
1974	2,549	4,567	7,841	12,063	16,219	498	653	825	1,058	1,297
1975	3,879	6,680	10,652	14,849	17,329	751	941	1,152	1,434	1,704
1976	5,521	9,022	13,244	16,181	16,434	1,059	1,279	1,529	1,831	2,072
1977	7,415	11,346	14,971	15,985	13,564	1,398	1,664	1,925	2,191	2,362
1978	9,459	13,421	15,545	14,429	10,342	1,792	2,069	2,300	2,463	2,513
1979	11,476	14,781	15,246	12,007	7,836	2,212	2,460	2,631	2,669	2,625
1980	13,357	15,411	13,902	9,923	6,418	2,629	2,817	2,875	2,837	2,643
1981	14,803	15,494	12,367	8,544	6,199	3,030	3,130	3,120	2,920	2,756
1982	15,780	14,858	11,186	7,978	6,972	3,397	3,401	3,271	3,082	2,879
1983	16,394	14,028	10,429	8,281	8,335	3,720	3,655	3,482	3,266	3,116
1984	16,597	13,388	10,316	9,305	9,800	4,050	3,879	3,718	3,539	3,432

Table 16-11. -- Cost of new construction, reconstruction, and resurfacing, 1965 to 1984, on the Federal-aid primary system, East North Central census division, for five levels of axle-weight limits.

(thousand dollars)

Sheet 1 of 3

Year	System 3. Federal-aid primary rural					System 4. Federal-aid primary urban				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	New construction costs									
1965	59,682	59,968	60,247	60,517	60,768	149,112	149,790	150,433	151,050	151,627
1966	197,145	198,173	199,173	200,142	201,038	92,583	93,003	93,402	93,785	94,143
1967	284,470	285,972	287,433	288,849	290,157	62,629	62,912	63,180	63,438	63,679
1968	342,265	344,106	345,896	347,630	349,232	34,000	34,166	34,323	34,473	34,612
1969	384,709	386,777	388,786	390,734	392,532	20,851	20,947	21,038	21,125	21,207
1970	422,483	424,762	426,975	429,121	431,101	16,215	16,296	16,373	16,446	16,514
1971	207,081	208,310	209,501	210,655	211,718	29,607	29,711	29,812	29,910	30,004
1972	147,068	147,922	148,750	149,552	150,291	53,292	53,520	53,738	53,948	54,145
1973	115,590	116,268	116,926	117,563	118,150	64,574	64,861	65,135	65,398	65,644
1974	88,396	88,898	89,386	89,858	90,293	72,044	72,374	72,688	72,989	73,271
1975	78,540	78,989	79,424	79,845	80,234	81,612	81,980	82,330	82,665	82,979
1976	68,761	69,151	69,530	69,896	70,234	94,762	95,200	95,615	96,013	96,384
1977	56,119	56,428	56,729	57,020	57,288	98,574	99,027	99,458	99,871	100,256
1978	53,022	53,325	53,618	53,902	54,164	100,519	100,977	101,413	101,830	102,221
1979	48,172	48,442	48,705	48,959	49,194	109,933	110,440	110,921	111,382	111,813
1980	42,604	42,834	43,057	43,274	43,473	114,461	114,991	115,493	115,974	116,424
1981	39,266	39,476	39,681	39,879	40,063	94,046	94,477	94,886	95,278	95,645
1982	56,275	56,574	56,864	57,146	57,406	104,408	104,877	105,322	105,750	106,151
1983	65,898	66,266	66,623	66,969	67,288	110,010	110,010	110,987	111,444	111,871
1984	73,534	73,961	74,375	74,776	75,145	115,689	116,218	116,719	117,200	117,650

Table 16-11. -- Cost of new construction, reconstruction, and resurfacing, 1965 to 1984, on the Federal-aid primary system, East North Central census division, for five levels of axle-weight limits.

(thousand dollars)

Sheet 2 of 3

Year	System 3. Federal-aid primary rural					System 4. Federal-aid primary urban				
	Single/tandem axle weight maximum limits, kips					Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Reconstruction costs									
1965	444,470	491,482	541,338	593,804	644,056	115,092	127,372	139,782	152,406	164,090
1966	414,142	451,848	489,740	528,070	563,046	102,574	112,194	122,064	131,762	141,398
1967	380,608	408,636	435,170	460,930	483,730	95,816	104,288	112,538	121,050	129,092
1968	346,522	366,894	387,008	406,928	422,764	89,864	97,486	106,176	114,244	120,982
1969	317,068	334,362	348,916	360,108	365,340	86,304	94,152	101,022	105,460	107,382
1970	292,884	303,944	311,228	312,386	304,514	84,374	89,960	92,984	91,986	89,860
1971	269,256	274,888	272,296	260,968	245,506	80,290	82,574	79,792	77,970	75,982
1972	245,252	241,770	230,600	213,268	201,146	73,700	70,942	69,706	67,418	64,166
1973	218,024	206,884	190,638	178,140	172,352	64,774	63,096	60,796	57,352	53,434
1974	188,204	172,840	159,774	155,328	147,298	58,022	56,192	52,986	49,218	43,368
1975	162,220	148,780	142,674	131,830	120,392	52,240	49,648	45,232	39,530	33,706
1976	138,048	129,302	121,426	109,486	93,666	46,328	43,232	38,046	30,938	27,338
1977	118,328	110,700	99,820	85,018	72,920	40,806	35,460	28,494	23,640	22,102
1978	102,274	92,586	78,972	63,592	58,038	33,690	27,840	20,828	18,550	17,702
1979	85,288	74,168	59,380	49,486	46,478	27,274	20,302	15,994	14,484	13,712
1980	70,524	57,648	43,652	38,516	35,346	20,962	14,556	11,998	10,786	9,694
1981	56,348	42,130	32,530	28,878	25,806	15,076	9,748	8,638	7,168	5,666
1982	42,568	28,954	23,572	19,560	17,320	9,926	6,476	4,752	3,958	3,300
1983	29,996	19,124	15,782	13,076	10,736	5,086	3,664	2,912	2,010	1,352
1984	19,014	13,054	9,782	7,318	5,866	3,270	1,944	1,230	694	620

Table 16-11. -- Cost of new construction, reconstruction, and resurfacing, 1965 to 1984, on the Federal-aid primary system, East North Central census division, for five levels of axle-weight limits.

(thousand dollars)

Sheet 3 of 3

Year	System 3. Federal-aid primary rural					System 4. Federal-aid primary urban				
	Single/tandem axle-weight maximum limits, kips					Single/tandem axle weight maximum limits, kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Resurfacing costs									
1965	18,223	20,271	22,467	24,824	27,198	2,429	2,742	3,077	3,417	3,747
1966	19,820	22,225	24,906	27,822	30,743	2,618	3,017	3,448	3,920	4,414
1967	21,414	24,261	27,437	31,064	34,780	2,865	3,362	3,950	4,604	5,293
1968	23,138	26,466	30,262	34,621	39,110	3,168	3,806	4,586	5,422	6,270
1969	25,014	28,886	33,266	38,033	42,756	3,559	4,334	5,223	6,172	7,140
1970	27,045	31,235	35,817	40,728	45,461	3,969	4,840	5,843	6,856	7,803
1971	28,921	33,284	37,939	42,648	46,440	4,449	5,405	6,417	7,399	8,193
1972	30,631	35,029	39,453	43,066	45,660	4,970	5,938	6,942	7,748	8,190
1973	32,230	36,471	39,954	42,524	43,675	5,524	6,508	7,379	7,854	7,888
1974	33,756	37,285	39,895	41,223	40,307	6,177	7,110	7,689	7,804	7,399
1975	35,010	37,832	39,495	38,915	36,373	6,841	7,597	7,858	7,577	6,972
1976	36,029	38,150	38,350	36,245	32,576	7,474	7,987	7,909	7,387	6,672
1977	36,954	38,109	36,884	33,724	29,262	8,005	8,268	7,895	7,257	6,562
1978	37,820	37,793	35,525	31,538	27,094	8,443	8,406	7,853	7,144	6,583
1979	38,457	37,315	34,302	29,861	26,333	8,729	8,429	7,733	7,046	6,745
1980	38,887	36,945	33,259	29,201	26,990	8,837	8,345	7,585	7,072	6,960
1981	39,176	36,653	32,698	29,615	28,966	8,799	8,164	7,428	7,059	7,098
1982	39,578	36,537	32,934	31,087	31,470	8,671	7,903	7,208	7,062	7,103
1983	40,055	36,688	33,802	33,327	34,253	8,389	7,577	7,100	7,025	7,016
1984	40,608	37,338	35,609	36,280	37,388	8,098	7,303	7,012	7,032	7,047

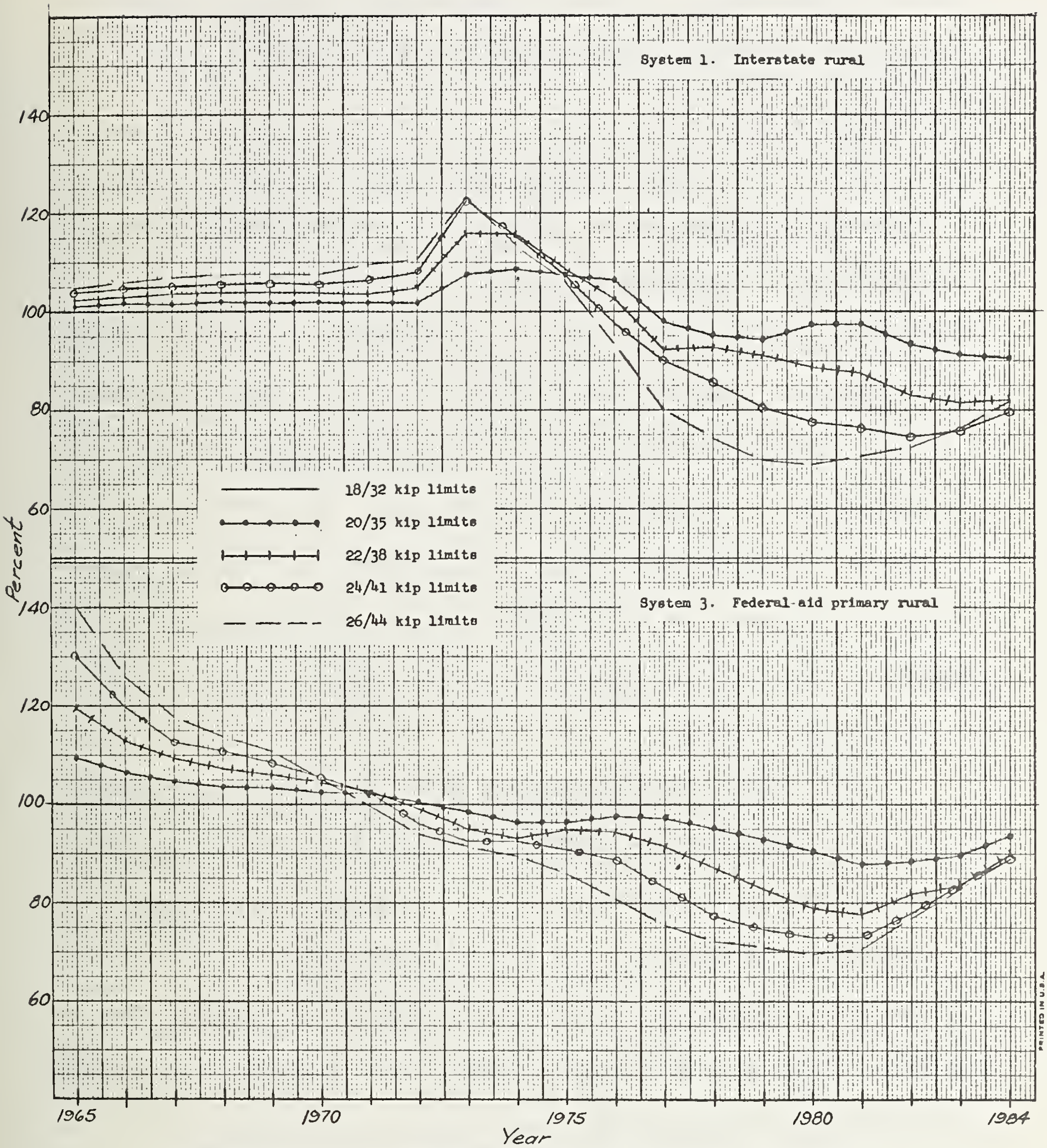

Figure 16-4 and 5. -- Total annual capital outlays, 1965 to 1984, for each increased axle weight limit expressed as a percentage of the base axle weight limit (18/32) for the Interstate and federal-aid primary rural systems, Census Division 5, East North Central.

forecasted to be on the basis of the existing axle-weight limits--18/32-kips. For the 20-year period, capital outlays at the base axle-weight limits are shown at 100 percent levels on a horizontal line.

The highest percentage increase in construction costs for the period from 1965 to 1985 is for the 26/44-kip axle-weight limit. Beginning with 1976 on the rural system and 1975 on the urban system, there is a decrease in total construction costs as compared with the prior years. In the comparison of the base axle-weight limit with the 20/35 increased axle-weight limit, this decrease occurs in 1977. The maximum increase in construction costs --139 percent of the base costs-- occurs in 1973 on the urban system for the 26/44-kip limit. The minimum costs --51 percent of the base costs-- occurs in 1977 on the urban system.

The total Interstate-system costs for the 20-year period are first controlled by the arbitrary scheme of completing the construction of the system by the end of 1972 at a uniform yearly rate. Thereafter, the annual construction cost, which is largely for resurfacing, is controlled by the shape of the survivor curve and the 20-year service life applied to the prior construction vintages. Some construction of additional lane-miles after 1972 is assumed to accommodate the increase in traffic volume on the Interstate system.

B. Primary Systems 3 and 4

The Federal-Aid primary rural system in the East North Central census division is shown in table 16-8 to have increasing capital outlays from 1965 through 1970 when a decrease starts, continuing to about 1981 before a second increase sets in. Again the cyclical behavior is a result of the increasing and decreasing rates of retirements of old pavements according to the retirement distribution based on the frequency curve and mileage of the original construction of the early vintages. Unlike the plan for the Interstate system, the primary system construction, 1965 to 1972, is a direct result of the retirement of the earlier vintages and the schedule of controlled existing mileage provided for in the computer input. These controlled mileage inputs provide for a general increase in the existing lane-miles on the system from 1965 through 1984. All of the increase in controlled mileage is considered new construction. Reconstruction is largely the replacement of retirements from construction of the vintages before 1957.

The greater amounts of reconstruction compared with the overall outlays explain a change from the trends noted for the Interstate system. The result is that, for the rural system, the increased axle-weight limits produce their greatest effects on construction cost in the early years. The highest percentage increase over the base condition is 140 percent in 1965, with the percentage trend decreasing to a low of 70 percent of the base level in 1980. The decreasing cost begins in 1973 for the 20/35-kip axle-weight level and 1971 for the 26/44-kip level.

On the Federal-aid primary urban system, the trends are similar. Greater cost effects are found at the higher (26/44) axle-weight limits. The percentage is lowest in the early years, increasing to a high of 127 percent of the cost at the base axle-weight limit in 1968 and then progressively decreases to a low of 87 percent in 1977. This difference from the trend on the rural system where the greater cost effects were found in the first years is assumed to be due to the higher design standards of the urban pavements and less mileage of early vintage on this system as compared with the rural system.

Table 16-8 as well as figures 16-4 and 5 show the pronounced shortening of average service life of existing pavement starting in 1965 to account for the probable more rapid reduction in the structural adequacy of the pavements under axle-weight limits increasing to 26/44 kips. But once the system mileage has been paved with pavement having a 20-year life and designed for the higher axle-weight limits, the capital outlays naturally decrease.

C. Percentage of Capital Outlays Required for New Construction, Reconstruction, and Resurfacing

Figures 16-6, 16-7, 16-8, and 16-9 for the East North Central census division and the four highway systems show the

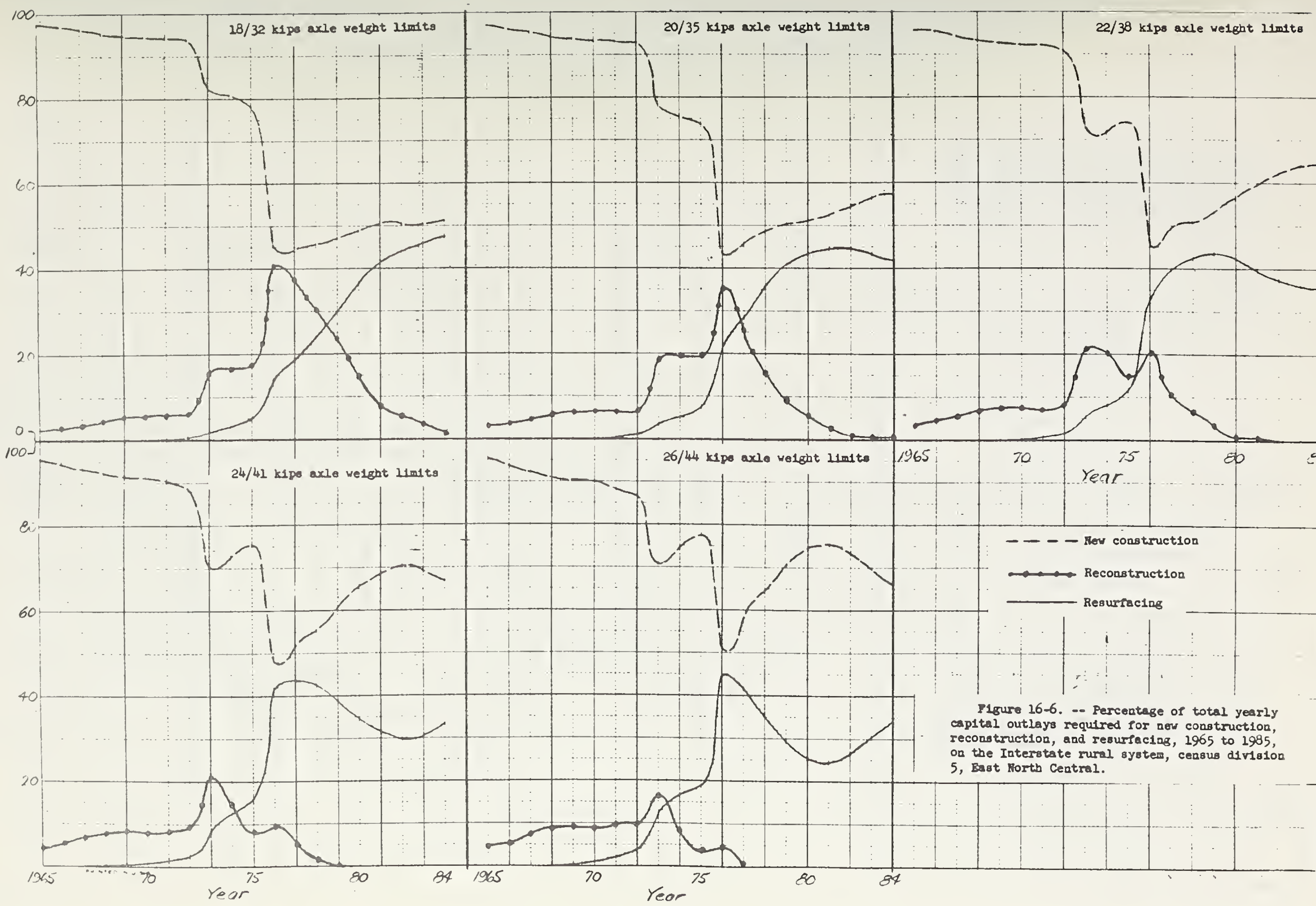

Figure 16-6. -- Percentage of total yearly capital outlays required for new construction, reconstruction, and resurfacing, 1965 to 1985, on the Interstate rural system, census division 5, East North Central.

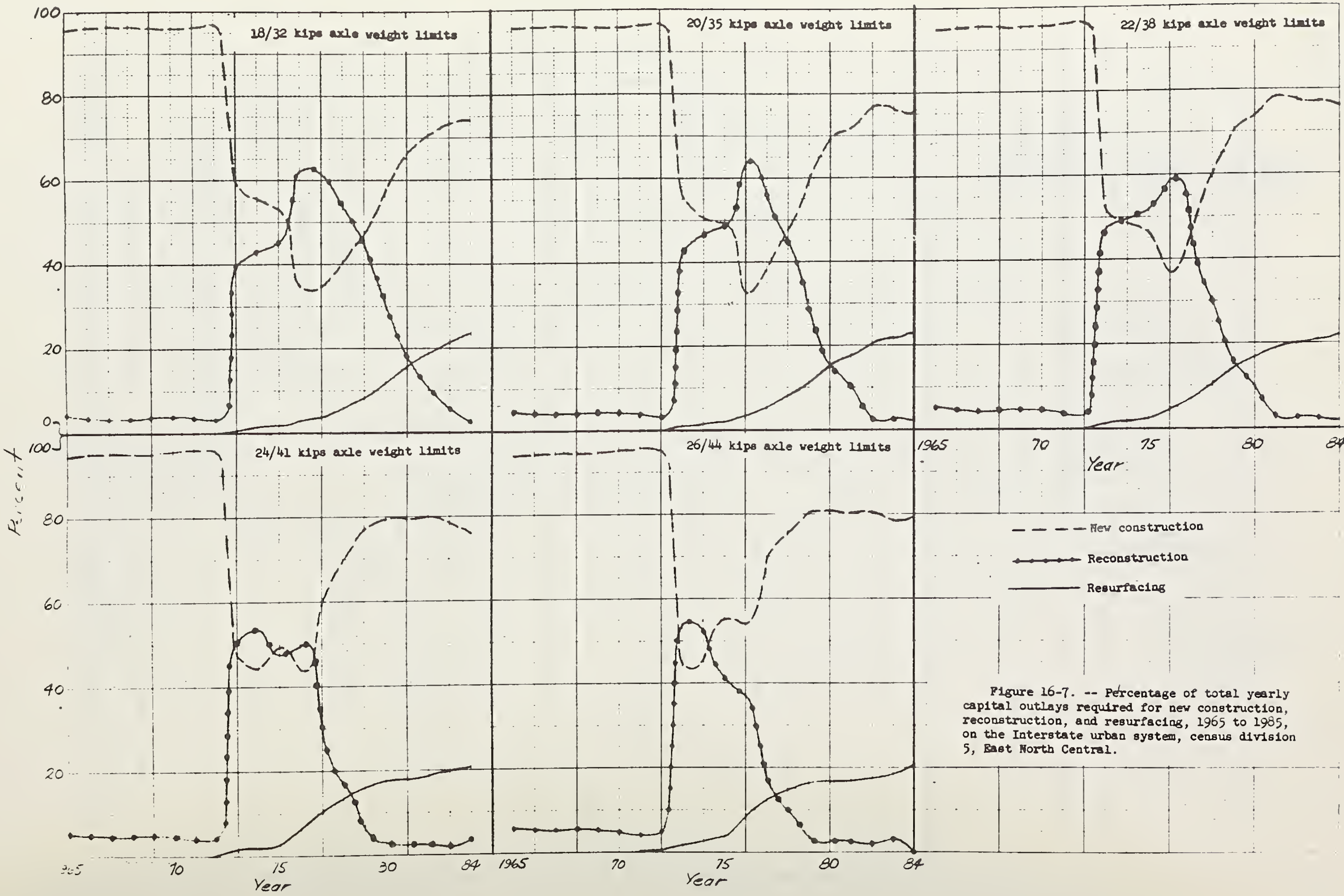

Figure 16-7. -- Percentage of total yearly capital outlays required for new construction, reconstruction, and resurfacing, 1965 to 1985, on the Interstate urban system, census division 5, East North Central.

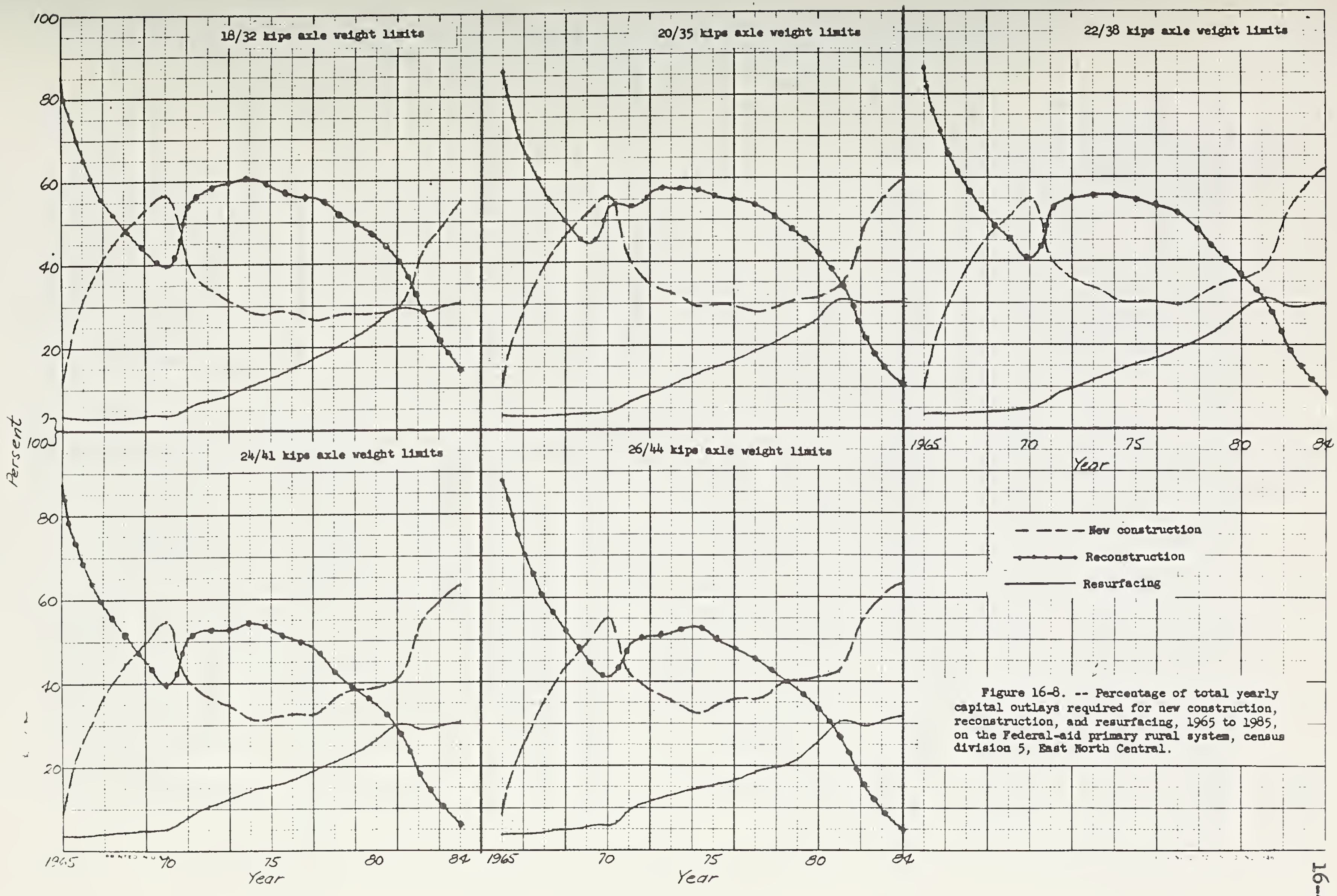

Figure 16-8. -- Percentage of total yearly capital outlays required for new construction, reconstruction, and resurfacing, 1965 to 1985, on the Federal-aid primary rural system, census division 5, East North Central.

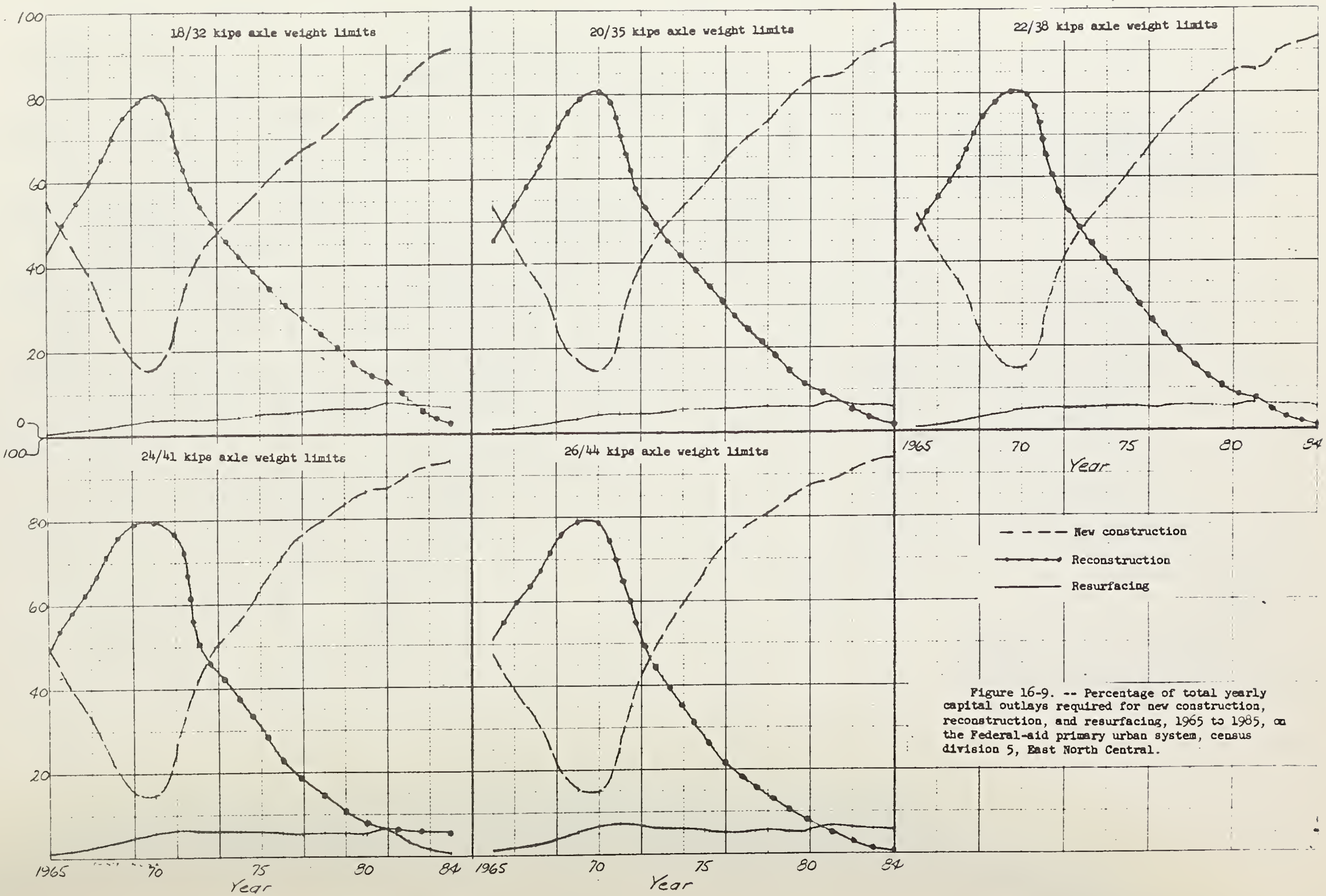

Figure 16-9. -- Percentage of total yearly capital outlays required for new construction, reconstruction, and resurfacing, 1965 to 1985, on the Federal-aid primary urban system, census division 5, East North Central.

percentages of the total capital outlays, year by year, divided between new construction, reconstruction, and resurfacing. The percentages for the primary system are somewhat different than for the Interstate system.

Each additional lane-mile of the Interstate system being a "new" mile of road designed to a high standard, there is relatively little reconstruction activity on either the rural or urban system (0 to 41 percent on the rural and 0 to 64 percent on the urban) as compared with the Federal-Aid primary system (5 to 88 percent on the rural and 1 to 81 percent on the urban). New construction activity is heavy throughout the projected period on both the Interstate and Federal-Aid primary systems but at different periods of time.

The 1972 planned completion date of the Interstate system results in the domination of new construction during the first ten years with a period of low activity in 1975, when because of increased projected traffic on the system, new lanes for added traffic capacity would be built, thereby increasing new construction activity. During the midpoint of the projected period, reconstruction contributes the most to the total capital outlays.

On the Federal-Aid primary system, reconstruction of old highways is the emphasis in the early years (1965-1972), particularly on the urban system. New construction on the rural system is on the rise in the early years and tends to stabilize between 1962 to 1981, when projected traffic would require new construction for increased traffic capacity. For the urban system, the trend of new construction is a decreasing one between 1965 and 1971, when the projection of urban versus rural travel results in a reversal of this downward movement in new construction outlays that holds throughout the remainder of the projected period.

Resurfacing activities on the Interstate rural and urban and Federal-Aid primary rural and urban systems are generally similar, both requiring small amounts of total capital outlay (0 to 47 percent for the Interstate and 3 to 26 percent for the Federal-Aid primary system). In both cases there is a continuous upward trend in the early years and a leveling out or decreasing movement in the closing years of the projected period.

These general trends are merely more rapid as the axle-weight limits are increased. In other words, where increased axle-weight limits result in greater amounts of reconstruction and resurfacing in the early years, because of the decreased service lives of these early vintage mileages, a lesser amount of reconstruction and resurfacing is required in the later years.

The effects of increased axle-weight limits on new construction are negligible, since only the pricing of the construction is increased, not the service lives, as is the case with mileage already existing (reconstruction and resurfacing activities).

D. 20-Year Total Capital Outlay

Table 16-9 sums up the yearly capital outlays in table 16-8 for the full 20 years for each of the four highway systems and ten census divisions. The left half of the table is the forecasted actual capital outlay and the right hand section of the table is the present worth, at 6 percent per year interest rate, of the yearly capital outlays summed up for the 20 years.

A comparison of the 20-year totals for the higher axle-weight limits with 20-year totals for the base axle-weight limits indicates the additional financing required over the 20-year period, should the higher axle-weight limits be adopted. It should be recognized that in table 16-9 the first four census divisions have no capital outlays for the 18/32-kip limit because their existing base axle-weight limit is higher. Likewise, the New England and Middle Atlantic census divisions have no base capital outlays for the 20/35 axle-weight limits because their limit is approximately 22/36 kips.

E. Capital Outlays on a National Basis

Table 16-12 gives on a national basis the 20-year totals of the 10 census divisions from table 16-9 and the outlays at the higher axle-weight limits expressed as a

Table 16-12.-Twenty-Year Total National Capital Outlays and Present Worth Values for Highways 1965-1984. By System and Axle-Weight Limits, Expressed in Absolute Values and Percentage of Base

System	20-Year Total Capital Outlays					Present Worth at 6 Percent of 20-Year Total Capital Outlays				
	Single/Tandem Axle Weight Limits. Kips					Single/Tandem Axle Weight Limits. Kips				
	18/32	20/35	22/38	24/41	26/44	18/32	20/35	22/38	24/41	26/44
	Thousand Dollars									
System 1. Interstate Rural	18,341,766	18,519,628	18,690,136	18,899,011	19,079,854	12,981,295	13,116,897	13,258,053	13,436,925	13,596,044
System 2. Interstate Urban	18,934,906	18,981,260	19,030,443	19,086,085	19,131,820	14,076,815	14,118,334	14,164,218	14,223,945	14,277,352
Subtotal	37,276,672	37,500,888	37,720,579	37,985,096	38,211,674	27,058,110	27,235,231	27,422,271	27,660,870	27,873,396
System 3. Federal-Aid Primary Rural	37,205,982	37,396,290	37,606,212	37,790,761	38,010,571	25,155,209	25,419,673	25,730,172	26,050,005	26,385,360
System 4. Federal-Aid Primary Urban	13,155,727	13,202,572	13,250,678	13,323,648	13,389,558	7,994,796	8,058,483	8,125,042	8,226,947	8,318,225
Subtotal	50,361,709	50,598,862	50,856,890	51,114,409	51,400,129	33,150,005	33,478,156	33,855,214	34,276,952	34,703,585
Grand Total	87,638,381	88,099,750	88,577,469	89,099,505	89,611,803	60,208,115	60,713,387	61,277,485	61,937,822	62,576,981
	Percentage of the 18/32 Kip Base									
System 1. Interstate Rural	100.0	101.0	101.9	103.0	104.0	100.0	101.0	102.1	103.5	104.7
System 2. Interstate Urban	100.0	100.2	100.5	100.8	101.0	100.0	100.3	100.6	101.0	101.4
Subtotal	100.0	100.6	101.2	101.9	102.5	100.0	100.7	101.3	102.2	103.0
System 3. Federal-Aid Primary Rural	100.0	100.5	101.1	101.6	102.2	100.0	101.1	102.3	103.6	104.9
System 4. Federal-Aid Primary Urban	100.0	100.4	100.7	101.3	101.8	100.0	100.8	101.6	102.9	104.0
Subtotal	100.0	100.5	101.0	101.5	102.1	100.0	101.0	102.1	103.4	104.7
Grand Total	100.0	100.5	101.1	101.7	102.3	100.0	100.8	101.8	102.9	103.9

percentage of the base limits. These national totals of capital outlays for the 20 years from 1965 through 1984 for the increased axle weights range from 100.2 to 104.0 percent of the base capital outlays without axle-weight limit increases. On a dollar basis, these increases would amount to $46,354,000 for Interstate urban 20/35 kip limits, and $738,088,000 for the Interstate rural, 26/44 kip limits. On a yearly basis, these increases in 20-year totals would average from $2,317,700 to $36,904,000.

Another comparison of the financing required under the four increased axle-weight levels is afforded by reducing the 20-year total capital outlays for each system to outlays per year per lane-mile of highway. The comparisons are given in table 16-13, showing the extreme differences in system cost and the relatively insignificant effects on total outlays obtained by increasing axle-weight limits. The greatest cost is found for the 26/44 axle-weight limit for all systems. By system, the Interstate urban requires the greater outlays. The greatest incremental differences are found between the 22/38 and 24/41 axle-weight limits. The only deviation from this trend is on the Federal-aid primary rural system, where the increase in axle-weight limit from 24/41 to 26/44 produces the highest incremental cost, $22.

Table 16-13.--Dollars cost of construction per lane-mile per year for the 20-year period 1965-1984 for each **axle-weight limit--National averages by highway system**

Based on lane miles in service December 31, 1984
(in dollars)

System	Single/tandem axle weight limits, Kips				
	18/32	20/35	22/38	24/41	26/44
System 1. Interstate Rural	4,523	4,567	4,609	4,661	4,705
System 2. Interstate Urban	19,418	19,465	19,516	19,573	19,620
Subtotal	7,411	7,455	7,499	7,552	7,597
System 3. Federal-Aid Primary Rural	3,654	3,672	3,693	3,711	3,733
System 4. Federal-Aid Primary Urban	8,754	8,785	8,817	8,866	8,910
Subtotal	4,309	4,330	4,352	4,374	4,398
Grand Total	5,243	5,270	5,298	5,330	5,361

10. PROBABLE CONSTRUCTION PROGRAMS AND REPLACEMENT OF BRIDGES

Table 16-8 illustrates a year-to-year variation in the financial requirements for different axle-weight levels, including the base level. It is not likely that any State highway department would want to provide such unequal year-to-year construction money immediately as higher axle-weight limits are permitted, with decreasing requirements in later years. As a practical expedient, the highway departments would carry on a program of gradual upgrading through reconstruction and resurfacing, as money became available. Further, it is probable that some additional maintenance expenses would be required to improve temporarily the quality of service of many miles of pavement pending the year when they could be reconstructed or resurfaced to adequate structural quality, as provided for in this analysis.

It is probable that the construction outlays indicated in tables 16-8 and 16-9 may be somewhat deficient in provision for the replacement of structures of older vintages or for strengthening their structural quality for service under conditions of increased axle-weight limit. However, provision is made in the base construction cost per mile for construction of completely new bridges on all mileage of new construction and reconstruction.

What and how many bridges would need to be replaced or strengthened for safe movement of traffic operating under higher axle-weight limits cannot be determined without a more detailed inventory of the bridges on the system. It is reasonable to expect that, under the increased axle-weight limits up to 22/38-kip limits, no bridges on the Interstate system and few on the primary system would require replacement or strengthening. At the 24/41-kip and 26/44-kip levels, a large number of bridges would need to be replaced or strengthened.

Certain bridges of inadequate structural strength for the higher axle-weight limits could be expected to be posted against higher loads until they could be brought up to standard. This practice would be comparable to present general practice of the States in protecting bridges of unsatisfactory structural strength against prossibly damaging loads. Such posting would not greatly interfere with truck transport, however, because the heavier trucks are more apt to travel on roads having bridges of adequate design. This condition could be expected at all limits probable except for the 24/41 and 26/44-kip limits.

11. AASHO REPORT ON THE PAVEMENT EVALUATION SURVEY--1962

In November 1962, the Committee on Highway Transport of the American Association of State Highway Officials submitted its "Report on the Pavement Evaluation Survey." 1/ This report was intended to show the effects of increased axle-weight limits in decreasing the remaining life of existing pavements and to show the added dollars required to resurface the pavements as needed. The study was made by 39 States in accordance with the Manual of Instructions issued by the Committee on Highway Transport in August 1962.

The AASHO study was restricted to resurfacing, the need for which was predicated on the PSI (present serviceability index) at the time of the study and as forecasted for ten years, with and without increases in axle-weight limits. Each State made the study for its State highways on a lane-mile basis. The axle-weight limits used were as follows: present base limits, 20/35 kips, 22/38 kips, and 24/42 kips.

The concepts and factors in the AASHO study vary so widely from those in this 1966 study of the desirable dimensions and weights of motor vehicles that any comparison of the final dollar requirements would probable lead to wrong conclusions. Some of these differences are set forth as follows:

1/ American Association of State Highway Officials. Pavement Evaluation Survey, by Committee on Highway Transport. R. R. Bartelsmyer, Chairman. 917 National Press Building, Washington, D. C. 20004. November 1962.

AASHO STUDY	BPR 1966 STUDY
1. For each axle-weight limit, all route sections below a PSI of 2.0 were resurfaced in 1963.	1. The first year (1965) was assumed to be a normal construction program. No catch up of deficiencies was provided for.
2. Highway costs include resurfacing only.	2. Highway costs include new construction, reconstruction, and resurfacing.
3. Study made State by State for 39 States on State highways grouped by basic axle-weight limits.	3. Study made on Federal-Aid systems grouped by census division.
4. Enforcement tolerance not considered.	4. Enforcement tolerance included in determining current axle-weight limits.
5. Resurfacing needs based upon the decrease in the PSI.	5. Reconstruction and resurfacing needs based upon retirement of prior construction as calculated from survivor curves.

12. TWENTY-YEAR CAPITAL OUTLAYS COMPARED TO REDUCTIONS IN TRUCK OPERATING COSTS

The truck operating costs presented in table 15-4B permit comparisons of 20-year truck operating costs with the 20-year highway capital outlays given in table 16-12. The first of two types of comparisons is shown in the left section of table 16-14 for each of four highway systems and the four systems combined. This section of the table shows the reduction in 20-year accumulated total truck operating cost compared with the 20-year accumulated incremental capital outlay for highway construction resulting from an increase in axle-weight limits. The figures are based on increases from the 18/32-kip single/tandem axle-weight limits to each of four higher axle-weight limits. The ratio of the truck operating-cost reduction to the increment of capital-outlay increase was shown for each of the increases in axle-weight limit.

A second comparison is shown in the right section of table 16-14. Here the reduction in truck operating costs and the increase in capital outlays for each of the 20 years, caused by an increase in axle-weight limits, have been discounted at a 6-percent interest rate to present-worth values and the results totaled. The ratio of the truck operating-cost reduction to the capital-outlay increase was then calculated for each change in the axle-weight limit from the base 18/32-kip single/tandem axle-weight limit.

Table 16-14 Ratio of the 20-year total truck operating cost reductions to increased total highway capital outlays from 1965 to 1984 at higher axle-weight limits - National total by highway system.

All costs are in millions of dollars.

Highway System and Item	Single/Tandem Axle Weight Limits in Kips				Single/Tandem Axle Weight Limits in Kips			
	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44	18/32 to 20/35	18/32 to 22/38	18/32 to 24/41	18/32 to 26/44
	Direct Dollar Basis				Basis of Present Worth at 6% Interest			
System 1. Interstate rural								
Total incremental truck operating cost reductions	2,208	4,913	7,778	10,244	1,168	2,596	4,103	5,404
Total incremental highway capital outlay increases	179	348	557	738	136	277	456	615
Ratio of truck cost reductions to capital outlay increases	12.3	14.1	14.0	13.9	8.6	9.4	9.0	8.8
System 2. Interstate urban								
Total incremental truck operating cost reductions	1,168	2,427	4,234	5,734	617	1,281	2,232	3,020
Total incremental highway capital outlay increases	46	96	151	197	42	87	147	201
Ratio of truck cost reductions to capital outlay increases	25.4	25.3	28.0	29.1	14.7	14.7	15.2	15.0
System 3. Primary rural								
Total incremental truck operating cost reductions	5,494	11,599	17,911	23,236	3,111	6,569	10,148	13,171
Total incremental highway capital outlay increases	190	400	584	805	264	575	895	1,230
Ratio of truck cost reductions to capital outlay increases	28.9	29.0	30.7	28.9	11.8	11.4	11.3	10.7
System 4. Primary urban								
Total incremental truck operating cost reductions	3,099	6,376	10,180	13,045	1,693	3,475	5,556	7,125
Total incremental highway capital outlay increases	47	95	168	234	64	130	232	323
Ratio of truck cost reductions to capital outlay increases	65.9	67.1	60.6	55.7	26.5	26.7	23.9	22.1
All systems combined								
Total incremental truck operating cost reductions	11,969	25,315	40,103	52,259	6,588	13,921	22,039	28,720
Total incremental highway capital outlay increases	462	937	1,460	1,974	506	1,069	1,730	2,369
Ratio of truck cost reductions to capital outlay increases	25.9	27.0	27.5	26.5	13.0	13.0	12.7	12.1

The ratios shown in table 16-14 are not directly comparable to the benefit-cost ratios in Chapters 10, 11, and 12. In these chapters a mile of highway construction was the basis for determining the benefit-cost ratio. Here in chapter 16 we are dealing with yearly capital outlays and with both operating costs and capital outlays related to highway systems on a nationwide basis.

In table 16-14, the capital outlays late in the analysis period are charged out against the motor vehicle cost reductions without regard to service life. In other words, the analysis would not include construction outlays from which benefits will be derived after the study period. Also, at the end of the 20-year period, the systems would be in a condition of high quality under the design standards required for each axle-weight limit. From then on, the rate of capital outlays to highway-system renewal will be much less than for the 20-year study period.

Note that, in table 16-14, the ratios are high, varying from 12.3 to 65.9 for the direct capital outlays (top section) and from 8.6 to 26.7 on the present-worth basis. These ratios are in harmony with those for Method 1-M in Chapter 10, and they serve as an additional check on the reliability of findings.

This analysis includes only axle-weight increase. Should the increase in vehicle length to Step 1 (Chapter 11) also be included, the resulting ratios would be at least 50 percent greater.

13. COMPARISON OF REPORTED CAPITAL OUTLAYS FOR 1964, BY HIGHWAY SYSTEM, WITH REQUIREMENTS UNDER HIGHER AXLE-WEIGHT LIMITS

A comparison of what highway construction would cost under increased axle-weight limits with what the construction cost under the existing limits for the year 1964 is presented in this section. The approach is simply to compare, for each of six highway systems and 10 census divisions, the total dollars of actual outlay for construction in 1964 with the cost of constructing the same number of miles at the per-mile cost computed by analysis Method 1-M for economy of axle-weight limits.

A. Assembly of Basic Information

Table 16-15 gives the miles of rigid and flexible pavement built in 1964 and the estimated incremental cost for this same mileage if it had been designed for each of the four levels of axle-weight limits above the base limits for each of the six highway systems and 10 census divisions. These incremental costs are the result of Method 1-M on economy of axle weight presented in Chapter 10. The costs include the pavement structure, shoulders, bridges, and earthwork. Table 16-15 also gives the total capital outlay for highway construction in 1964 under the then existing axle-weight limits.

Table 16-15 does not present a true relationship of the miles built and total capital cost in 1964, because the

Table 16-15. -- Additional 1964 highway construction cost by axle-weight limits and the percentage increase over 1964 actual capital outlays had higher axle-weight limits been provided for [1]

Dollar amounts in thousands

System	Miles built		Total added construction cost [2] computed from the base single/tandem axle-weight limit [3] to increased limits				Total system capital cost					Total system capital cost at increased limits as a percentage of 1964 actual cost			
	Rigid pavement	Flexible pavement	20/35	22/38	24/41	26/44	Actual cost of 1964 axle-weight limits	Calculated cost at increased axle-weight limits: 20/35	22/38	24/41	26/44	20/35	22/38	24/41	26/44
1. Interstate, Rural	1,087	918	7,410	15,525	25,581	34,798	1,814,426	1,306,149	1,606,731	1,840,007	1,849,224	100.6	101.0	101.4	101.9
2. Interstate, Urban	185	116	1,131	2,534	4,199	5,950	1,381,787	859,722	1,007,383	1,385,986	1,387,737	100.1	100.3	100.3	100.4
Subtotal	1,272	1,034	8,541	18,059	29,780	40,748	3,196,213	2,165,871	2,614,114	3,225,993	3,236,961	100.4	100.7	100.9	101.3
3. Federal-aid Primary, Rural	1,093	10,196	11,939	27,076	43,341	59,077	1,251,451	845,495	1,053,240	1,294,993	1,310,528	101.4	102.6	103.5	104.7
4. Federal-aid Primary, Urban	338	864	2,125	4,688	7,721	10,614	733,592	500,808	570,811	741,313	744,206	100.4	100.8	101.1	101.4
Subtotal	1,431	11,060	14,064	31,764	51,062	69,691	1,985,043	1,346,303	1,624,051	2,036,306	2,054,734	101.1	102.0	102.6	103.5
5. Federal-aid Secondary, Rural	293	18,564	4,360	10,096	16,222	22,441	717,142	489,708	637,610	733,364	739,583	100.9	101.6	102.3	103.1
6. Federal-aid Secondary, Urban	31	462	797	2,088	3,699	5,303	75,591	52,262	70,124	79,290	80,894	101.5	103.0	104.9	107.1
Subtotal	324	19,026	5,157	12,184	19,921	27,744	792,733	541,970	707,734	812,654	820,477	101.0	101.7	102.5	103.5
Total All Systems	3,027	31,120	27,762	62,007	100,763	138,183	5,973,989	4,054,144	4,945,899	6,074,953	6,112,172	100.7	101.3	101.7	102.3

1/ Based upon additional highway construction cost incurred with each projected increase in axle-weight limits as applied to 1964 constructed centerline mileage and capital outlay cost. The 1964 mileages represent completed roadway projects as reported from "Highway Statistics," 1964, Table SF-11, p. 80.

2/ Includes construction cost of: pavement, shoulders, earthwork, drainage, and bridges.

3/ Base axle weight limits are as follows: (1) 22/38 for NE and MA; (2) 20/35 for San and SAS; (3) all other census divisions are 18/32. The added cost is that increase from the cost at the base limits to the cost at the higher axle weight limits.

reported capital cost includes projects for which no paving was constructed. This discrepancy is on the conservative side, because the total miles assumed to have been paved in 1964 at the higher axle weights produce a higher total incremental cost above the actual cost than would the correct mileage of paving.

Table 16-15 also gives the computed total system capital cost for each of the four higher axle-weight limits. In the last four columns, these final costs are compared on a percentage basis with the reported 1964 capital costs.

B. Comparative 1964 Capital Costs for the Six Systems

On a census division basis, the ranges of percentage increase in construction costs in 1964 over actual costs for increased axle-weight limits are as follows:

System	Single/tandem axle weight limits, kips				
	18/32	20/35	22/38	24/41	26/44
1. IR	---	0.3 to 0.9	0.3 to 1.8	0.3 to 2.7	0.6 to 3.5
2. IU	---	0.0 to 0.3	0.0 to 0.6	0.1 to 0.9	0.1 to 1.1
3. FAPR	---	0.3 to 3.4	0.6 to 6.9	0.4 to 10.4	0.9 to 13.7
4. FAPU	---	0.2 to 0.5	0.4 to 1.2	0.3 to 2.4	0.6 to 3.6
5. FASR	---	0.2 to 2.4	0.3 to 4.8	0.1 to 7.4	0.3 to 10.0
6. FASU	---	0.5 to 3.1	1.1 to 6.3	1.2 to 9.5	2.1 to 13.5

The above tabulation indicates that on a percentage basis the least affect of increased axle-weight limits is found on Systems 1 and 2, Interstate rural and urban. The percentage increases in cost are the greatest on Systems 5 and 6, Federal-Aid secondary rural and urban, with the urban having the greater percentage increase. The reason for this trend can be assumed to be the much higher standards of design for the Interstate system compared to the secondary system, thus creating greater need for improvement on the secondary system when higher axle-weight limits are applied. Lane for lane, in the axle-weight economy study, all six systems have the same basic design, varying only by the E 18-kip axle applications. The higher 1964 construction costs on the Interstate system provide for a much higher dollar amount for the percentage base than do the lower 1964 costs on the secondary system.

A review of table 16-15 indicates no general trend on a census-division basis. It is noted that the greater costs, on a percentage basis, are found in those census divisions (5 through 10) having the 18/32-kip limits. This is disproved to some extent for the East South Central census division, where the general trend indicates the least effects of increased axle-weight limits on rural systems. As would be expected, the greater the axle-weight limit increase, the greater the cost differential.

On a national basis the comparative construction costs in table 16-15 are summarized as follows to show the dollars of added cost in 1964 if the construction had been designed for the higher axle-weight limits:

Increase in National Construction Cost for 1964 Compared with Actual Costs for Higher Axle-Weight Limits

In 1,000 Dollars

Highway System	Single/tandem axle-weight limits in kips				
	18/32	20/35	22/38	24/41	26/44
1. Interstate rural	---	7,410	15,525	25,581	34,798
2. Interstate urban	---	1,131	2,534	4,199	5,950
3. Federal-Aid primary rural	---	11,939	27,076	43,541	59,071
4. Federal-Aid primary urban	---	2,125	4,688	7,721	10,614
5. Federal-Aid secondary rural	---	4,360	10,096	16,222	22,441
6. Federal-Aid secondary urban	---	797	2,087	3,699	5,303
All systems		27,762	62,006	100,915	138,177

The total dollars for each highway system in this tabulation are relatively small sums, considering the total mileage involved. Should all the 1964 construction have been designed for the 22/38-kip axle-weight limits--the approximate maximum limits now legal in any state--the increased construction outlay would have been only $62,006,000, of which $27,076,000 would have been for the Federal-Aid primary rural system.

CHAPTER 17

GENERAL SUMMARY AND EVALUATION

At the risk of some repetition, a few final comments are presented in this chapter to add to the reader's understanding of the subject and to aid him in evaluating the results of the research reported upon.

With only minor exceptions, this report on the desirable maximum dimensions and weights of motor vehicles fulfills the initial research plan for it. The several studies included in it not only developed suitable methods of research, but achieved both qualitative and quantitative results for each of the variable factors related to the desirable dimensions and weights. This statement does not mean, however, that there are not many factors still needing study.

1. GENERAL SUMMARY

The analysis of the State laws and the truck weight studies indicate two significant factors needing improvement. The first is lack of uniformity among the States in maximum limits on dimension and weight, and its unfavorable consequences to the costs of highway transportation. The second factor is the high percentage of vehicles with overweight axles and excessive gross weights. Overloading combined with liberal enforcement tolerances, higher legal limits for certain commodities, and unprecedented issuing of special permits for trips made by overdimension and overweight vehicles actually have nearly the same effects on the pavement as would be expected from an increase in legal limits without tolerance and without legal exceptions for hauling of certain local commodities.

Without doubt, unexpectedly high economy can be realized by increasing axle-weight limits, gross weight limits, and vehicle length limits. The indicated economy is so high that its existence should not be questioned. The additional annual outlay for highway capital construction occasioned by immediate increase in motor vehicle weight limits would be small--perhaps one percent--in the expenditures for highway construction.

The fear on the part of many individuals and the public at large that increased vehicle weight limits would quickly destroy existing pavements is not in agreement with past experience. Axle-weight limits have been raised over the last 45 years from about 8,000 to 23,500 pounds per single axle and, during this time, the number of heavy axle applications and their average weights applied to the pavements have increased. Yet over the 45 years that these increases have been experienced, improvement and reconstruction of highways for this reason alone has been a gradual yearly factor. The highways have been financed from year to year without pinpointing any particular part of the financing that has resulted from increasing axle and gross weight limits.

In the event that the State laws were altered to provide for higher axle-weight and gross weight limits, it is not likely that an increase in the rate of deterioration of highway pavements would be specifically noticed. The analysis, however, shows that any expected increase in the rate of reconstructing pavements that might result from increased weight limits would be many times offset by a decrease in the cost of highway trucking operations.

It may be taken for granted that the highway trucking industry will continue to grow, both to meet the demands of increasing population and to provide improved quality of service. The rate of growth might be retarded or prevented by changes in technology or through the development of improved modes of transport that are more competitive with highway truck transportation. It was not the purpose of this report to investigate such matters, but they are mentioned here only to emphasize the potential and the fact that there is no immediate foreseeable end to the need for providing increased facilities for highway trucking operations, with or without changes in axle-weight limits.

The research findings in this report point to a high economy for the 3-unit combination with a length limit of 65 or

70 feet and a gross weight limit of about 110,000 pounds. A gross weight-limit increase does not necessarily mean an increase in highway costs, provided that a control is placed upon axle weight and axle spacing together with the overall length of the vehicle.

With approximately 14 States legalizing the 65-foot long combination in 1965, 1966, and 1967, it may be concluded that other States will follow in 1968. So ideal a vehicle from the point of view of transport operation is the 65-foot long combination that its eventual spread to the eastern and southern States may be taken for granted, especially since such vehicles could be permitted without increasing highway costs and perhaps with no net detriment to traffic as a whole. The move to the eastern seaboard has begun with recent (1967) legislation in Delaware and Maryland.

2. EVALUATION

Again it is emphasized that unless overall highway transport costs per payload ton-mile are reduced or the service values of highway transport are greatly increased, there is no solid basis for increasing the legal maximum dimension and weight limits. A sizeable economy to be obtained by increased vehicle length and weight limits would still remain, even after discounting heavily the reductions in truck operating costs to be achieved with the increased limits arrived at in this research and increasing somewhat the estimated highway costs that would result. In other words, although the policy followed herein was conservative (low benefits and high costs), even should the trucking benefits be cut in half and the incremental highway costs doubled, worthwhile economy would still be found. This statement is made because of some uncertainty as to just what would be the trucking practice and fleet composition under increased limits of dimension and weight. These factors were determined by sound logic and careful procedures, but other analysts may come up with different results. A more thorough examination of the effects on bridges may be in order, particularly for the longer combinations with variation in axle arrangements.

Because in many instances, the AASHO pavement design formulas produced pavement design depths materially less than are now being used by the States, some question may be raised as to whether the analysis by Method 1-M reaches the correct answer. But here again the margin of economy is so great that the question is only academic.

The analyses in Chapter 16 leading to an estimate of the highway financing required for the period from 1965 to 1985, with and without increases in axle-weight limits, may justly be questioned. Although the total dollar requirement may depart from what other analysts would estimate, the differentials between the requirements with and without increases in axle-weight limits are sound. The yearly distribution of reconstruction and resurfacing over the 20-year period is just one of many probable results, depending upon the procedures adopted to estimate the yearly needs for reconstruction or resurfacing.

Continued studies of the subject of the desirable dimensions and weights of vehicles will no doubt lead to improvements in methodology and greater proof of certain conclusions, but this report offers a substantial and reliable basis upon which to consider highway-department and other public policies and State and Federal laws affecting the dimensions and weights of motor vehicles.

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