THE UNIVERSITY OF MICHIGAN

MICHIGAN PAVEMENT PERFORMANCE STUDY

Five Year Summary Michigan Pavement Performance Study

Evaluation of Pavement Performance as Related to Design, Construction, Maintenance and Operation

1957 - 1962

By
WILLIAM S. HOUSEL

Project of the

Michigan Highway Planning Survey
Work Program HPS-1 (27)
In Cooperation With
U.S. Department of Commerce
Bureau of Public Roads

December, 1962

OFFICE OF RESEARCH ADMINISTRATION · ANN ARBOR

UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

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MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

ORGANIZATION

I Cooperating Agencies

A. U. S. Department of Commerce - Bureau of Public Roads

B. Michigan State Highway Department

C. University of Michigan - Department of Civil Engineering (Contractor)

II Sponsors

A. 1957-1959

1. Michigan Trucking Association

2. American Trucking Associations, Inc.

3. Automobile Manufacturers Association

B. 1959-1962

1. Michigan State Highway Department (Contractee)

III Sponsor Representatives and Advisory Personnel

A. 1957-1959

1. Wm. W. Johnston - Managing Director, Michigan Trucking Association

2. H. A. Mike Flanakin - Highway Engineer, American Trucking Associations, Inc.

3. R. A. Lill - Chief of Highway Engineering American Trucking Associations, Inc.

4. T. F. Creedon - Highway Engineering Advisor Automobile Manufacturers Association

5. John H. King - Manager, Motor Truck Division Automobile Manufacturers Association

B. 1959-1962

1. Howard E. Hill - Managing Director, Michigan State Highway Department

2. William W. McLaughlin - Testing and Research Engineer, Michigan State Highway Department

3. O. L. Stokstad - Design Development Engineer, Michigan State Highway Department

4. E. M. Noble - Highway Planning Survey Manager,* Michigan State Highway Department

FINANCING

I <u>Contracts and Expenditures</u>

A. Trucking Associations' Sponsorship University of Michigan Account 50824 — $ 109,737.41

1 Sep 57 - 31 Aug 58	--	$ 45,000.00	
1 Sep 58 - 30 Nov 58	--	19,000.00	
1 Dec 58 - 31 Aug 59	--	45,000.00	
(Overrun)	--	737.41	

B. Michigan State Highway Department Sponsorship University of Michigan Account 03088 — 374,739.70

1 Jul 59 - 31 Dec 59	--	$ 29,061.56	
1 Jan 60 - 30 Jun 60	--	26,908.50	
1 Jul 60 - 30 Jun 61	--	140,577.64	
1 Jul 61 - 30 Jun 62	--	142,196.27	
1 Jul 62 - 31 Dec 62	--	35,995.73**	

$ 484,477.11

* H. S. Bengry, 1959-60; A. C. Sherman, 1961

** December Estimate - $6,500.00

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

PREFACE

It is the purpose of this five year summary to assemble and review without duplicating a large number and variety of reports that have been submitted during this period for the information and use of the Michigan State Highway Department and others who have had an interest in the study. The opening discussion is intended to present a resume which touches on the high points of the pavement performance study, its background, objectives, results obtained over the five year period, and their practical application to the design, construction, maintenance, and operation of a state highway system.

Three series of reports are included as an integral part of this five year summary. The published papers or those presented at meetings without publication in recognized proceedings have been assembled in their original form as a part of the review. The second series, Departmental Reports, with the few exceptions noted have had or are being given official distribution to those connected with the investigation in one way or another. Reports submitted as part of the five year summary have been bound separately to make them more readily available to those interested in the subject of any specific report.

The third series, listed as Supplementary Reports, represents miscellaneous dissemination of information in several forms including short letter-reports on problems of immediate interest and papers submitted for preliminary review which may or may not have been published in final form.

Some of this information may have had only limited departmental distribution and is not being included in this final assembly of reports other than by brief review.

Information given in the listed reports has been considered in preparing the review although specific reports may not be designated. In other cases, reference to specific reports may be made by number designation and the reader may go to the report itself for more detailed information. Finally, it may be pointed out that this review and those supplementary reports which have been given only limited distribution may be obtained by those who may so desire by application to the Michigan State Highway Department.

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

ACKNOWLEDGMENTS

During the five year period that this comprehensive study of pavement performance has been in progress there have been a number of agencies taking part in the joint effort and many individuals who have made important contributions to the project. Without their interest and support, it would have been impossible to carry this work to what it is hoped will be considered a successful conclusion. Preceding the text is an outline of project organization and financing; the supporting agencies and their representatives have been named and the magnitude of financial support of the project from several sources has been given.

The direct supervision of the project for the Michigan State Highway Department has been the responsibility of W. W. McLaughlin, Testing and Research Engineer. O. L. Stokstad, Design Development Engineer, has been a frequent advisor and co-worker whose efforts have been particularly valuable in applying the results of this research to the everyday problems and operations of the Highway Department. W. M. Aldous was Project Supervisor for the University of Michigan in 1957-1958; his initiative and ability played a large part in the planning and assembling of the project equipment and instrumentation. Henry W. Wallace, as Associate Research Engineer, has been Project Supervisor for the University of Michigan since 1959, and has been responsible for direct supervision and innumerable but important details of operation. John E. Allen, as Field Survey Supervisor, has been with the project from the beginning, and his

knowledge and experience with mechanical and electrical equipment as well as in supervision of field personnel has been invaluable to the project. Others on the research staff who have been engaged in the project work are too numerous to name individually, but it is their devotion to and interest in the work, beyond the basic requirements of their employment, that have been most important in accomplishing project objectives. Authorship of some of the supplementary reports will provide at least some recognition of their efforts.

From the standpoint of the University of Michigan, the project has provided the opportunity for a considerable number of graduate students whose field of interest was in soils and highway engineering to take part in productive research, gain practical experience, and supplement other sources of financial support for their education.

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

CONTENTS

P-1 - "Pavement Profile Surveys to Correlate Michigan Design Practice with Service Behavior", Proceedings, Highway Research Board, Vol. 38, 1959. (Co-author, O. L. Stokstad)

P-2 - "Legal Weight Limitations on Motor Vehicles", Paper presented at 44th Annual Michigan Highway Conference, Grand Rapids, Michigan, March, 1959.

P-3 - "Service Behavior as a Criterion for Pavement Design", Paper presented at 48th Annual Meeting of Western Petroleum Refiners Association, San Antonio, Texas, March, 1960.

P-4 - "Cumulative Changes in Rigid Pavement with Age in Service", Highway Research Board Bulletin No. 328, 1962. (Paper presented at 41st Annual Meeting of Highway Research Board, Washington, D. C., January, 1962)

P-5 - "Design, Maintenance, and Performance of Resurfaced Pavements at Willow Run Airfield", Highway Research Board Bulletin No. 322, 1962. (Paper presented at 41st Annual Meeting of Highway Research Board, Washington, D. C., January, 1962)

P-6 - "The Michigan Pavement Performance Study for Design Control and Serviceability Rating", Proceedings, The International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1962.

B. Departmental Reports

D-1 - Frost Displacement Profiles. September, 1959. Revised, November, 1959.

D-2 - Measurement of the Riding Quality of Bridge Decks. November, 1959.

D-3 - Cumulative Changes in Rigid Pavement with Age in Service. Preliminary Draft, January, 1960. Report Postponed to January, 1962.

D-4 - A Special Report on Pavement Profiles of Ingham County Roads. December, 1959.

D-5 - The Performance of US-31, Muskegon - Grand Haven Expressway, as Determined from Roughness Profiles. March, 1961.

D-6 - The Performance of the Bay City - Midland Expressway as Determined from Roughness Profiles. March, 1961.

D-7 - Load-Deflection Study of a Bituminous Pavement on M-55. April, 1961.

D-8 - Bridge Deck Roughness Data for Grand Rapids Area Bridges. June, 1961.

D-9 - Bridge Deck Roughness Data for Grand Blanc Area Bridges. October, 1961.

D-10 - Performance of Detroit-Brighton Expressway on I-96 from Pleasant Valley Road to Novi Road as Determined from Roughness Profiles. December, 1962.

D-11 - Special Roughness Profile Study - Fenton-Clio Expressway, US-23, and Battle Creek Bypass, I-94 (US-12). December, 1962.

D-12 - The Performance of Benton Harbor - New Buffalo Expressway on I-94 from Stevensville to M-60 as Determined from Roughness Profiles. December, 1962.

D-13 - The Performance of Muskegon - Grand Haven Expressway on US-31. (Special Study Project No. 1) December, 1962.

D-14 - Load-Deflection Study of Selected Flexible Pavements (Special Study Projects No. 1, 3, and 5) December, 1962.

D-15 - The Performance of Rockwood-Monroe Section - Detroit-Toledo Expressway, I-75, as Determined by Roughness Profiles. (Special Study Project No. 10) December, 1962.

D-16 - Feasibility Study of Equipment for Recording Continuous Load-Deflection Profiles. December, 1962.

D-17 - Comparative Performance of Reinforced Concrete Pavement and Plain Concrete Pavement with and without Bituminous Resurfacing - Special Sections on I-94, The Detroit Industrial Expressway. December, 1962.

D-18 - Computer Program for Converting the Modified Michigan Roughness Profile to a True Surface Profile. December, 1962.

D-19 - Manual for Operating and Servicing the Truck-Mounted Profilometer. December, 1962.

D-20 - The Performance of I-96, Portland to M-66. (Special Study Project No. 12) December, 1962.

C. Supplementary Reports

S-1 - Pavement Roughness on Concrete Bridge Decks. February 24, 1959.

S-2 - Proposal for Continuation of Michigan Pavement Performance Study. December 9, 1959. Revised, December 23, 1959.

S-3 - Summary of Pavement Profile Surveys, 1958-1960 - General Motors Proving Grounds, Milford, Michigan. November 23, 1960.

S-4 - Progress Report and Present Status of Michigan Pavement Performance Study. December 14, 1960.

S-5 - Riding Qualities of Bridge Decks - St. Joseph River Bridge on I-94 near Benton Harbor. January 9, 1961.

S-6 - Fowlerville Automatic Scale - Truck Profilometer Profiles of March 4, 1961. March 7, 1961.

S-7 - Road Classification and All-Season Trunkline. March 17, 1961.

S-8 - Riding Qualities of Bridge Decks - I-96 Bridge over 28th Street, Grand Rapids, Michigan. March 23, 1961.

S-9 - Fowlerville Automatic Scale - February 7, 1961 Truck Profilometer Data. March 27, 1961.

S-10 - Riding Qualities of Bridge Decks - I-96 over Thornapple River. April 7, 1961.

S-11 - Michigan Pavement Performance Study - Proposed Work Program for July, 1961 through June, 1962. April 15, 1961. Revised, May 1, 1961 and May 9, 1961.

S-12 - Fowlerville Automatic Scale - May 5, 1961 Hand Profilograph Data. May 11, 1961.

S-13 - Indiana Pavement Profiles - US-20. November 13, 1961.

S-14 - Initial Profilometer Survey of December 20, 1961 - Southfield Expressway from Ford Road to Joy Road. December 27, 1961.

S-15 - Profilometer Data on Bituminous Resurfacing Projects Fb 25011 C1-R and Mb 30062 C2-R. January 2, 1962.

S-16 - Pavement Roughness - M-21 Exit Ramp to I-96. Hand Finish vs. Machine Finish. December 28, 1962.

S-16B- M-21 Exit Ramp to I-96. Machine Finish vs. Hand Finish. July 13, 1962.

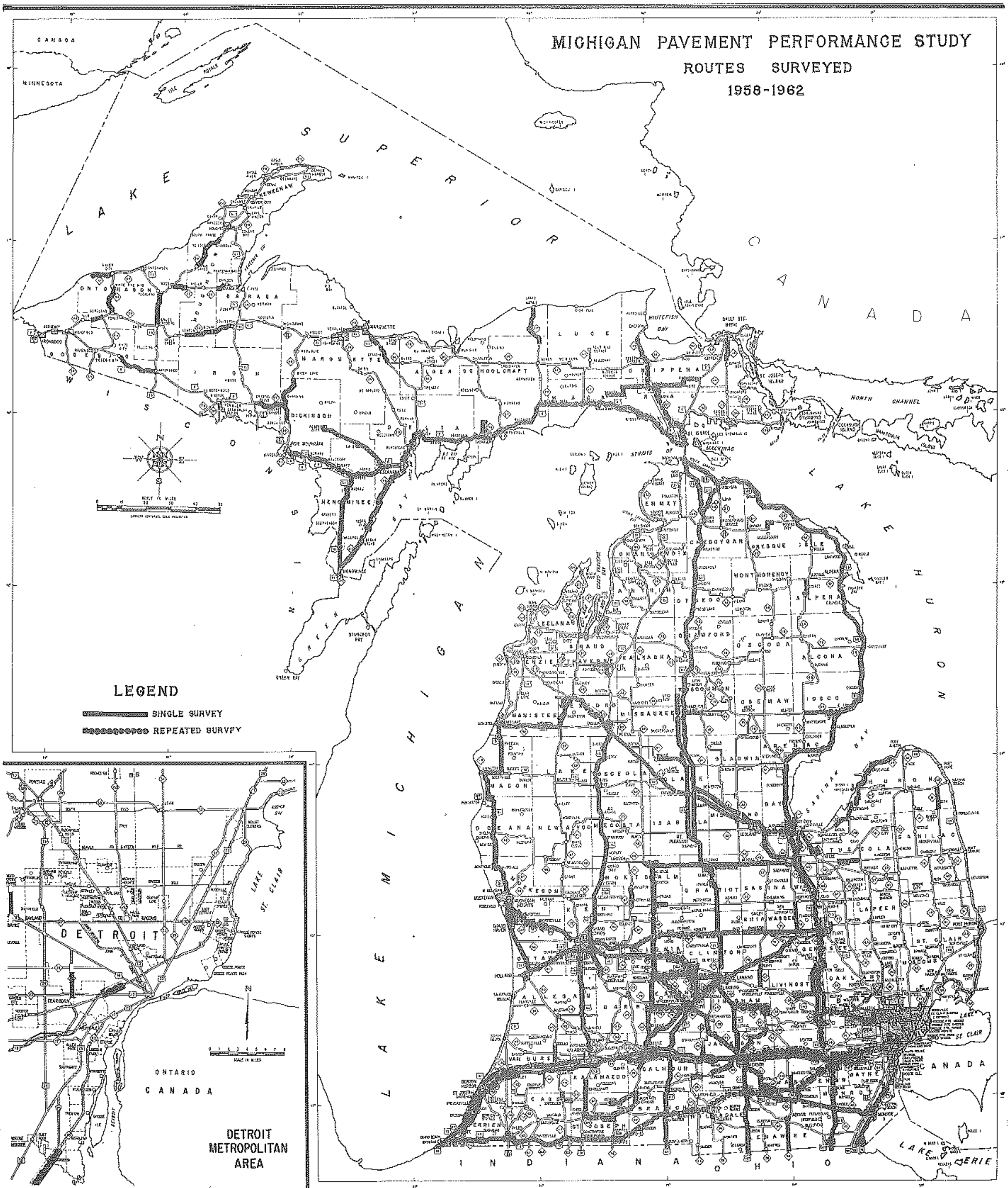
S-17 - Cumulative Changes in Rigid Pavement with Age in Service. January 23, 1962. (Preprint copies of HRB Paper)

S-18 - Design, Maintenance, and Performance of Resurfaced Pavements at Willow Run Airfield. February 14, 1962. (Preprint copies of HRB Paper)

S-19 - Roughness of US-131 in Kent County, South of Grand Rapids. March 13, 1962.

S-20 - The Michigan Pavement Performance Study for Design Control and Serviceability Rating. July 6, 1962. (Preprint copies of International Conference Paper)

S-21 - Examples of Riding Quality of 1961 Bituminous Pavements - US-27 North of M-55; Control Sections 72014 C1 and 72014 C2, US-27. July 9, 1962.



MICHIGAN PAVEMENT PERFORMANCE STUDY
ROUTES SURVEYED
1958-1962
LEGEND
SINGLE SURVEY
REPEATED SURVEY
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
CANADA
WISCONSIN
INDIANA
OHIO
LAKE ERIE
DETROIT METROPOLITAN AREA
ONTARIO CANADA
DETROIT
LAKE ST. CLAIR

"The human understanding when it has once adopted an opinion . . . draws all things else to support and agree with it. And though there be a greater number and weight of instances to be found on the other side, yet these it either neglects and despises, or else by some distinction sets aside and rejects; in order that by this great and pernicious predetermination the authority of its former conclusions may remain inviolate."

Francis Bacon
(1561-1626)

"When you can measure that of which you speak, and express it in numbers, you know something about it."

Lord Kelvin
(1824-1907)

EVALUATION OF PAVEMENT PERFORMANCE

AS RELATED TO

DESIGN, CONSTRUCTION, MAINTENANCE, AND OPERATION

INTRODUCTION

Evaluation of pavement performance on a large scale by the procedures used in this investigation was undertaken in the belief that carefully controlled observations of existing pavement under actual service conditions and environment would provide the answers to some of the most perplexing problems facing the highway engineer. The first year, from September, 1957, through the first half of 1958, was devoted largely to selecting procedures and designing, planning, and assembling equipment. In spite of a disappointingly long shakedown period for the truck-mounted profilometer, considerable mileage of pavement profile was recorded in the first year and a half.

In the five years that the Michigan Pavement Performance Study has been in progress, almost 10,000 lane miles of profile have been recorded. The progress by years is shown in the following table; the routes surveyed are shown on the small scale map following the table of contents. On some of these routes only one lane has been surveyed, normally one of the traffic lanes. On a large part of the mileage, particularly on new construction and certain roads of special interest, all lanes, including both traffic and passing lanes, have been surveyed.

TOTAL MILEAGE OF RECORDED PAVEMENT PROFILE

1958 ----	1,969.2
1959 ----	2,128.2
1960 ----	1,769.4
1961 ----	2,366.8
1962 ----	1,535.6
	9,769.2

This large mileage of recorded pavement profile and supplemental data represent a volume of basic information on pavement condition and performance, the value of which has been only partially utilized to date. This review and the accompanying supplementary reports will illustrate the use of this information in design, construction, maintenance, and operation of the Michigan trunk line system. However, its value as a pavement inventory and a foundation on which to build future applications of practical value can be realized only by its continued use and by keeping it up-to-date and growing as the highway system grows.

In the opening discussion of the Michigan Pavement Performance Study it is appropriate and useful to supply some background information as a matter of record. Condition surveys of existing pavements as a check on design and a basis for more effective utilization of natural conditions and materials in highway construction are not new. As pointed out in several of the published reports, this approach had been used for many years and was the fundamental basis for Michigan design of the roadway structure.

Prior to the current study, definite criteria for measuring pavement performance in a quantitative manner had been set up and put into practice under field conditions.[1,2] The primary function of a pavement is

1 W. S. Housel, "Report on the Evaluation of Service Behavior of Plain vs. Reinforced Concrete Pavement", University of Michigan Research Institute Report No. 2053-1-S, for Wire Reinforcement Institute, May, 1954.

2 W. S. Housel, "Pavement Performance as Related to Design", Proceedings, Fortieth Annual Michigan Highway Conference, 1955.

to provide a smooth riding surface supplying safety, comfort, and economy to the highway user. Recognizing this, riding quality has been defined in terms of a Roughness Index (RI), expressing the cumulative or total inches of vertical displacement per mile measured from the recorded pavement profile.

It was also recognized that the structural properties of the pavement would control its ability to endure under the combined stresses of continuous load repetition and the rigors of its environment. It seemed logical that failure to survive or inadequacy as a structure would be reflected in cracking or loss of structural continuity even before riding quality was affected. Timely maintenance or corrective steps would depend on early identification of weakness, so a Continuity Ratio was adopted as an independent quantitative measure of structural adequacy. The continuity ratio was defined as the ratio of the uncracked slab length of a pavement divided by 15. The control length of 15 feet was selected as a measure of the normal subdivision of a rigid concrete slab due to shrinkage, warping, and curling under temperature, moisture, and other environmental influences. It was considered that such environmental effects did not reflect structural inadequacy; thus, slab lengths of 15 feet or more would not be considered evidence of structural weakness.

The adoption of these criteria and their application to condition surveys of existing pavements in 1957 at the beginning of the current survey was not a generally recognized approach, but definitely a minority viewpoint. Design committees of the Highway Research Board, as well as many others, had become committed to the road test approach. As a matter of fact, the first published paper, P-1, included in this report was presented by Mr. Stokstad and the writer by invitation in lieu of including field surveys as an alternate to the satellite tests in the recommended procedures then being circulated by those committees to follow up the AASHO Road Test.

Having established criteria and general procedures for the pavement performance surveys, the truck-mounted profilometer with its electronic recording instrumentation was developed as the major piece of equipment. It was modeled after that designed by F. N. Hveem and used by the California Department of Highways. It was selected as the most practical under field conditions and state highway department operation to collect and record a large volume of pavement profile data. Many types of road roughometers have been described and used with varying success, but the choice had to be made from those which were readily available. There was little time to devote to devising and developing instrumentation, and the California machine was operating efficiently and, with some modifications, met the needs of the Michigan study.

Modifying the available provision for recording a continuous pavement profile in one wheel track, a double recording system was adopted which provided profiles in both the outer and inner wheel paths in one operation. Electronic integrating instrumentation was added to record the cumulative roughness in inches of vertical displacement for each quarter-mile. More details on the profilometer and its operation are given in the reports included as part of this summary.

USE OF PAVEMENT PROFILE SUMMARIES

The first objective of this review is to provide convenient access to the large volume of accumulated pavement performance data, the ultimate value of which will be realized only in proportion to its continued use.

Summary of Pavement Survey Data

The Control Section Log Records of all roads which have been surveyed during the past five years have been assembled to serve as the basic index to the Summary of Pavement Survey Data. These Control Section Log Records are the standard forms on which the history and present status of all contract sections in the Michigan trunkline system have been recorded. They are in fact a physical inventory of the state highway system and are in constant use by the Department in compiling highway statistics relating to the physical condition of Michigan roads and future needs.

These records, while somewhat voluminous, are the most convenient and readily available means of identifying and locating any particular section of state trunkline system and obtaining the essential facts concerning it. In the compilation of Control Section Log Records included in this review, all construction contracts for which pavement profiles have been recorded are shown with the mileage, number of lanes surveyed, the date or dates of surveys, and the chart roll number on which the pavement profile is recorded. There are 1700 rolls of pavement profile charts on file at the Willow Run Soils and Paving Laboratory, with a total of some 32 miles of chart covering 9,769 miles of recorded pavement profile. At the present time, these basic records are in the custody of the University and are adequately housed and readily available for reference as long as present space assignments are maintained.

The next step in utilization of the pavement profile data involves the use of the Summary of Pavement Survey Data. This summary is compiled in five sections, one for each of the five years from 1958 through 1962. In it are tabulated in detail all of the data gathered in connection with the pavement profile surveys. A typical data sheet is included in this review as

Appendix B. In 1959 this table was revised to its present form, in which the first five columns give the identification information, including route number, contract number, pavement type, year built, and district and control number. The next nine columns give corollary information for each profile survey, including roll number, date of survey, weather conditions, pavement condition, temperature of air, pavement, and subgrade, length of survey, and direction and lane number. The next four columns give the wheel path and its three roughness index values, in inches of cumulative vertical displacement per mile: the average for the contract section, and the minimum and maximum values for the smoothest and roughest quarter mile, respectively.

The next column gives the adequacy classification established for pavement evaluation or rating used in connection with the pavement performance study. (See Reports P-1, P-2, and P-3) The last three columns give the data on structural continuity of the pavement, including the continuity ratio of the original or "as built" pavement and the continuity ratio and cracking index at the time of the survey.

At the beginning of the tabulations for each year, a special listing has been compiled to serve as an index to the data sheets which follow. The routes surveyed are listed by number, e.g., US-2, M-21, etc., followed by page number and location where the particular section will be found. The tabulation also shows the month of the survey and the mileage surveyed for each route by month and the total for the year. In the index tables, the trunklines surveyed are assembled in three groups, designated as frost sections, special projects, and pavement inventory. This grouping was not completely established in the first several years, but has been followed in the tabulation of data since 1959. The tabulated pavement survey data have been assembled under this same grouping system for the purpose of making more accessible the data related to specific subjects of interest.

The frost sections refer to projects included in special studies of frost displacement. Special projects are those selected by O. L. Stokstad in the last several years for special consideration because of design features of particular interest, as listed in Appendix A. Roads not falling in either of the first two categories are referred to simply as part of the pavement inventory involved in the long range use of pavement profile data. As in the index summaries at the beginning of each year's tabulation, the tabulations of detailed data are assembled in the numerical order of the route numbers.

UTILIZATION OF PAVEMENT PROFILE DATA

In the title of this review it is indicated that pavement performance data finds application in design, construction, maintenance, and operation of highways. It is not always recognized that a highway department actually has four major functions which may be so delineated in describing different phases of its operations. However, in planning this review of the pavement performance study, it did appear not only appropriate but necessary to so classify highway activities in order to accurately illustrate the usefulness of pavement profile data.

Design Correlation

The primary objective of the Michigan Pavement Performance Study was to provide more accurate and discerning techniques for checking pavement design and detecting weakness in service performance. It seemed entirely logical that changes in the pavement surface or profile would reflect the integrated result of the various stresses and strains to which a pavement is subjected, originating from variations in the supporting subgrade below or from repeated load application and weather cycles above. While the uncontrolled variables of environment seem much more difficult to gauge than the more precise relationships of applied load and reaction in the pavement structure, they are nevertheless the influences under which pavements must endure. Every one of these variables, controlled or uncontrolled, has its effect on the pavement surface; whether or not they can be identified is a test of the observer and the methods of analysis brought to bear on the problem.

At first it was thought that an initial reference profile would have to be recorded and then, after a sufficient period of time had elapsed to produce a measurable change, a subsequent profile would measure the change. This meant that a period of years, perhaps many, would be required before definitive changes would become apparent. It came then as an unexpected bonus when, after a considerable volume of profile data had been accumulated, it turned out that roads which had been in service for varying periods of time under varying conditions of service and environment fell into definite patterns of behavior that could be defined in terms of pavement roughness, structural continuity, and related characteristics of the pavement. This discovery opened the door to a great storehouse of valuable data when it became apparent that the entire highway system was the final testing ground and that the many years these roads had already been subjected to traffic was the ultimate road test, which was merely awaiting analysis.

From the standpoint of pavement design, the reports which are a part of this review contain many examples in which the responsible factors in pavement performance have been clearly identified in terms which demonstrate them to be subject to design control. The overriding importance of soil conditions and drainage stands out in many of these examples and demonstrates the soundness of Michigan design, which follows the unspectacular but time-tried principle that it is the subgrade which "does, in fact, carry the road and the carriage also".

A few illustrations drawn from the supplementary reports and summarized briefly may be used for illustration. The following table lists the correlation between riding quality and drainage taken from Report P-1. It should be noted that drainage as listed includes internal drainage as controlled by soil texture and ground water level.

Route Number	Figure Number	Service Period Years	Roughness Index Inches per Mile OWP	IWP	Drainage	Riding Quality
US-112	7A	32	72	75	Fair	Very Good
	7B	32	291	395	Poor	Prohibitive*
M-25	8A	28	91	66	Excellent	Good to Very Good
	8B	36	218	175	Poor	Very Poor
M-41	12A	22	383	365	Poor	Prohibitive*
	12B	22	73	75	Good	Very Good
M-36	16A	19	84	77	Excellent	Good
	16B	19	363	282	Poor	Prohibitive*

* Outside the tentative rating scale

Other design correlations presented in Report P-1 include the poor performance of short concrete slabs without load transfer at the joints (See Fig. 17), as compared to the performance of another road (See Fig. 12B), also having comparatively short slabs, but with load transfer provided. While there were other factors involved to some degree, the contrast in these two roads was so sharp that the comparison is still valid, with the first pavement becoming extremely rough in its period of service and the second maintaining very good riding quality over a considerably longer period of time.

The most interesting feature of the rough pavement in the preceding example is the characteristic saw-tooth pattern produced by tilting and faulting of the short slabs. This illustrates the unique value of an actual pavement profile which goes beyond the roughness index derived from it. Such a profile is a realistic picture of the pavement itself and a physical condition that has been produced by some specific factors among a variety of influences that may have been present. Such a profile is as individualistic as a signature, reflecting characteristics that can be fully appreciated only by examining the profile itself and the physical conditions associated with it in whatever detail is necessary to reading the pavement's past history.

This leads to perhaps the most important consideration in evaluating pavement performance from condition surveys. The roughness index or some other quantity derived from the pavement survey may adequately reflect the present riding quality or serviceability of the pavement. This in itself is an important consideration and may be useful in several respects. However, from the standpoint of pavement design one must know not only the extent to which a pavement has deteriorated or lost riding quality but <u>why</u>

it has reached that particular level of serviceability. This is the crux of the situation and the point at which the actual pavement profile shows its real value, as it may provide an insight into events in the past history of the pavement which have left no other clues. (See Fig. 13 and Page 17, Report No. P-6)

There are a number of other examples of the surprising consistency with which accurate pavement profiles and the quantitative criteria derived from them single out abnormalities in pavement behavior or unusual conditions which have affected pavement performance. For more complete study of all such information, reference should be made to the reports submitted as part of the five year summary.

The discussion of the evaluation of pavement performance as related to design may be concluded by summarizing some of the major findings on design correlation during the five year study.

1. Michigan's current design standards for rigid pavements carrying present legal axle loads are adequate for all-season service without load restriction. In thousands of miles of pavement profile surveys of concrete pavements which by design or natural conditions meet these standards, there has been no significant evidence of loss in serviceability over periods up to thirty years due to unlimited repetition of legal axle loads.

2. On the other hand, concrete pavements that have been designed and built to these standards suffer a cumulative increase in roughness of 4 to 5 inches per mile per year due to environmental and climatic factors. Chief among these deteriorating influences are the temporary pavement displacements caused by frost action and temperature differentials. Frost displacement appears to originate in the freezing of moisture which accumulates in the subgrade and granular bases and subbases immediately beneath the pavement surface. Temporary displacements, which reach a maximum in late winter, largely disappear in the summer but leave a residual roughness which is the primary source of the

cumulative loss in riding quality. (See Report P-4, Figs. 1 through 9)

3. Flexible pavements with bituminous surfaces built to equivalent all-season standards for present legal axle loads show comparable performance characteristics and evidence of cumulative changes of about the same order of magnitude. The mechanics of flexible pavement are such that cumulative loss of riding quality is not produced by the same type of residual roughness as in rigid pavements but, on the other hand, there is some evidence of measurable differentials in roughness due to traffic. These considerations and results from short time studies are inconclusive, although they give some promise that the loss in riding quality may proceed at a lesser rate than in rigid pavements. However, sufficient data over longer periods of service and comparable conditions are still to be accumulated to supplement the present study before these important questions can be answered. (Report P-6, Figs. 14 through 18 and Table 2)

Construction Practice and Pavement Performance

It has been stated that pavement performance surveys have shown that current design standards provide adequate load-supporting capacity. However, these same surveys show that in terms of potential riding quality, the benefits of adequate design are not being fully realized. Involved in this problem are plans and specifications and construction control which fail to achieve the maximum potential performance from well-designed pavements. This appears to fall largely in the field of construction practice so is being discussed under that heading. The accumulation of a large volume of pavement profile data has brought to light, or perhaps emphasized by supplying the figures, several deficiencies in construction practice.

Granting that the end product in building a pavement is riding quality, then current specifications and inspection procedures fail to conserve or protect a considerable percentage of a pavement's potential life. "Built-in" roughness has become a common term only since pavement condition surveys have included accurately recorded profiles and the roughness index associated with them. One of the first observations that was somewhat surprising to those unaware of the problem was the sharp contrast between the roughness index of bridge decks and bridge approaches and that of the adjacent roadway pavements finished with conventional paving equipment. Another observation on "built-in" roughness is the almost universal characteristic of greater roughness in the outside wheel path or the edge of the pavement. This has been taken to indicate that irregularities in form setting were more completely reproduced close to the forms and damped out, to some degree, in the center of the concrete slab.

As data accumulated in considerable volume, they have been reported to the Department so that possible corrective measures could be studied. Departmental Reports D-2, D-8, and D-9 and Supplementary Reports S-1, S-5, S-8, and S-10 have all reported field survey data compiled on the roughness of bridge decks and bridge approaches. Summarizing of representative data from these reports shows roughness indexes ranging from about 100 to 300, averaging around 200 inches per mile. In terms of the tentative rating of riding quality, the average performance of bridge decks would be described as very poor to extremely rough. Bridge approaches fall in about the same classification.

Turning next to hand finishing of paving, which occurs in special cases where machine finishing is impossible or has been eliminated by special permission, the results are comparable to those obtained on bridge decks. Supplementary Reports S-16 and S-16B dealt with the roughness of hand finished pavement on the ramps of the grade separation at the intersection of M-21 and I-96, near Grand Rapids. The roughness on the first ramp, reported in S-16, varied from 167 to 191 inches per mile, which would be rated from poor to very poor. The second ramp, reported in S-16B, showed a roughness index varying from 145 to 154, falling on the border line between acceptable and poor, but certainly not to be considered as high quality work.

Occasionally some unusual conditions come to light as pavement profiles are being analyzed which may be related to construction methods. Such a case has been described in Supplementary Report S-19, and also in Report P-6 (See Fig. 13 and Page 17). In this case, a comparatively new pavement on US-131 was reported by the Department as being extremely rough, and a pavement profile survey was requested. On the basis of the profile, this section was rated extremely rough, with a roughness index of 233 inches per mile and a saw-tooth pattern, particularly in the outer wheel path, almost identical to that caused by the tilting of short slabs previously reported on US-24A and Shown in Fig. 13A in Report P-6. The close comparison in terms of roughness index and profile was not repeated on the inner wheel path of the US-131 pavement, where the saw-tooth pattern was damped out and the roughness index dropped to 105 inches per mile. The sharp displacements in the outer wheel path were repeated at intervals of approximately 10 feet. Although there were no joints or cracks in the pavement to produce faulting at these intervals, spacing of these displacements did coincide with the 10 foot length of the sections of the paving forms. The evidence pointed to careless form setting and it was concluded that this was the source of this abnormal and unusual built-in roughness. Parenthetically, it may here be noted that the considerable effort devoted to grinding down high spots did not appear to have been particularly effective in producing improved riding quality.

Supplementary Report No. S-14 is of interest as an illustration of high built-in roughness resulting from a combination of conditions during construction, which may or may not be justified. Initial roughness ranged from 107 to 124 inches per mile, with an average of 115 for all lanes. This project was discussed with the project engineer who considered that the high roughness was due to inadequate equipment and inexperienced workmen.

The principal item of objectionable equipment was the "bull float" (longitudinal float) finishing machine which was also in poor condition. This type of equipment is not suited to finishing steep alternating grades (3 per cent) with short vertical curves and has been prohibited on subsequent work of this nature. The "bull float" has a 10-foot long straight float positioned at a slight angle to the center line. This oscillates longitudinally as it moves back and forth across the pavement and simultaneously advances. (See Fig. 24-11, Page 24-21, Wood's Highway Engineering Handbook). The front end tends to gouge into the slab going uphill and the rear gouges going down. The finished pavement surface passes the 10-foot straight edge test easily, but may still be rough riding.

In discussing examples where construction practice has resulted in abnormally high built-in roughness, it would distort the picture to ignore the equally numerous examples where high grade workmanship has produced superior riding quality. The fact that there are such examples is particularly significant because it demonstrates that it is within the range of common practice in pavement construction to produce such superior results. There is then all the more reason why poor workmanship and inferior riding quality need not be accepted.

Several examples of superior riding quality may be cited in both concrete pavements and asphalt pavements. In Fig. 1 in Report P-4 there are identified a group of three concrete pavements, discussed on Page 13, built with roughness indexes of 50 inches or less per mile and five other projects which, allowing for normal increase in roughness, would have had "built-in" roughness of less than 50 inches per mile. It is significant that five of these eight projects were built by two contractors who had established a reputation for doing high quality work. Other illuminating examples were also cited in the same report in the discussion of quality of workmanship.

Other examples of excellent construction performance were given in Departmental Reports D-5 and D-6, where the contractors made a special effort to provide superior riding quality. On US-31, the Muskegon - Grand Haven Expressway, a heavy-duty asphaltic pavement, the initial roughness index values ranged from 20 to 40 inches per mile. On the Bay City - Midland Expressway, a concrete pavement, the average roughness index values ranged from 34 to 58 inches per mile. In terms of maximum and minimum for any quarter mile, roughness index values ranged from 20 to 84 inches per mile, indicating less uniformity in finishing than on the US-31 flexible pavement. Supplementary Report No. S-21 presents data on a number of contracts totalling more than 30 miles of bituminous expressway construction on I-75 or US-27 in which the job average of roughness index values ranged from 17 to 49 inches per mile, with only a few quarter mile maximum values above 50.

Other observations of direct correlation between pavement performance and construction conditions are given in several reports on special projects, some of which will be cited as examples to illustrate the more prevalent sources of poor performance which appear to be related to construction practice.

The Fenton - Clio Expressway on US-23, now I-75, discussed in Departmental Report No. D-11, has been the source of comment by a number of observers reporting certain sections south of Flint which have shown abnormal increases in roughness and other signs of deterioration. Mr. Stokstad first called this to the attention of the Pavement Performance Study group in his memorandum of March 14, 1960. At that time he commented on the number of pop-outs and numerous transverse cracks; he suggested frost heaving, settlement, and perhaps inferior aggregates as possible contributing factors.

Subsequent surveys reported in D-11 confirm these observations and, as shown in Table III, there are significant differentials in both the roughness indexes and continuity ratios in the sections south of M-78, toward Fenton, and the sections north of Flint. In the same table, the grouping of contractors is indicative of their general performance on other projects and is further evidence that "built-in" roughness may be as much a reflection of the characteristics of the contractor as it is of physical conditions associated with the project.

On the other hand, it is equally important to identify the particular elements in pavement construction which provide the opportunity for poor workmanship and are thus a primary source of poor performance. Enough has been said of built-in roughness as an immediate result of careless finishing.

Attention may next be given to those factors which result in early and excessive deterioration in the pavement surface. Non-uniform compaction of granular bases and subbases and failure to provide uniform subgrade support for the pavement structure are the most familiar sources of poor pavement performance. An abnormal decrease in structural continuity shown by excessive crack development and deterioration of the pavement surface may be due to inferior concrete, non-uniform settlement of the supporting subgrade and bases, or a combination of these two basic deficiencies. There are a number of examples of this in the series of reports submitted in the course of the pavement performance study and doubtless many more in the pavement profile data that have not yet been analyzed.

Several examples may be selected for illustration. Perhaps the most striking example is the rapid deterioration of the Detroit Industrial Expressway, from Willow Run to Detroit. Built during the war years, the sand subbase over clay was adequate in thickness; however, failure to provide adequate and uniform compaction through field density control, combined with the elimination of steel reinforcing and further complicated by poor control of concrete mixtures, made the poor performance inevitable. These conditions were clearly revealed by comprehensive investigations subsequently made by the Department. Regardless of whether or not these conditions could be excused as emergency construction, the results were nevertheless revealing as the consequence of poor construction practice.

After this pavement had been stress-conditioned through years of service under heavy traffic, it was rehabilitated by bituminous resurfacing to recover acceptable riding quality. It was hoped that it could then provide a period of years of improved service without rapid deterioration. The results presented in Departmental Report D-17 are rather fragmentary, but the abnormally high rate of increase in roughness of the plain concrete sections is not an encouraging indication. As shown in Table 1 and Fig. 4, the newer reinforced concrete pavement shows an average increase in roughness of 4.5 inches per mile per year, while the older plain concrete, resurfaced in 1955-56, shows an increase in roughness about three times as great.

Another of the "Special Projects" selected by Mr. Stokstad for close attention was on I-75, the Detroit-Toledo Expressway, and is briefly reported in Departmental Report No. 15. Again, the early results are not encouraging, although it isn't clear as yet whether the excessive cracking is due to deficiencies in design or in construction. The increase in roughness index has not yet been sufficient to reveal lack of subgrade support and it may be some years before comparative results become definitive.

Application of Pavement Profile Data to Maintenance

Data from condition surveys of existing roads are of direct value in several phases of maintenance, with particular reference to the pavement structure. The rate of change in both roughness and structural continuity, when compared with normal cumulative changes, may reflect unfavorable physical conditions or weakness in design and construction that may be possible to correct. Cracking in concrete pavements due to environmental factors or load repetition or to the combination of both is a natural development; hence, joint and crack maintenance is accepted as normal and considered a routine operation in the early stages of pavement life. In older pavements or in those which for one reason or another are subject to excessive cracking, filling of joints and cracks may become ineffective or prohibitive. Such conditions may be the signal for resurfacing or early reconstruction, beyond the scope of maintenance.

In bituminous pavements, both roughness and loss of structural continuity have significance comparable to those in rigid concrete pavements, but the evidence of structural deterioration is not as easy to evaluate in quantitative terms. Identification and classification of cracking, patching, and other types of surface deterioration in bituminous pavements have been worked out by technical committees of the Highway Research Board and also in connection with the AASHO Road Test. The final reports from that test are perhaps the most readily available and the most authoritative for present use. Consequently, they will be considered in some detail.

In the AASHO Road Test, the roughness index and continuity ratio used in the Michigan pavement performance surveys are combined in a single numerical index, defined as the Present Serviceability Index (PSI). In Appendix A of Report P-6, submitted as part of this final report, the Michigan roughness index and the cracking and patching as a measure of structural continuity in a flexible pavement were translated into terms of the Present Serviceability Index.

The first step in this procedure is illustrated in Fig. 20 of P-6, where the Michigan Roughness Index (RI) was converted into a function of the AASHO Slope Variance ($\sqrt{SV}$) by a theoretical equation developed by Irick. Conversion of comparable data from a number of different projects is shown in Fig. 20 as representative of the general correlation. In Fig. 21 is shown on a semilogarithmic plot the relationship between the Present Serviceability Index and the Michigan Roughness Index derived from the rating of 49 rigid pavements by a panel of observers selected to extend AASHO Road Test results to existing pavements. To test the validity of this relationship, comparative values of both measures of serviceability or performance have been plotted from six flexible and six rigid pavements in Michigan.

The preceding discussion of quantitative measures of pavement performance has two objectives. The first objective was to show that data from the Michigan Pavement Performance Study can be readily translated into terms of the AASHO Serviceability Index and conversely that useful results from that test could be put into practice in Michigan. The second objective was to apply the pavement performance criteria to maintenance and point out relationships of important practical significance.

Directing attention now to the second objective, it seems particularly important to take note of the fact that deterioration of the pavement surface, reflecting loss in structural integrity, is of primary importance as an independent guide to timely maintenance and should not be buried by the statistical combination involved in reducing pavement performance to a single numerical coefficient such as the Present Serviceability Index (PSI). Recognition of this fact has entered into some of the most recent discussion of this subject and it seems reasonable to suppose that pavement performance criteria may be adjusted accordingly.

As a first example of the use of pavement condition data from field surveys as a guide to maintenance, reference is made to Report P-5, which is devoted largely to describing maintenance of the airfield pavement at Willow Run. Maintenance of the airfield paving was a basic responsibility assumed by the University of Michigan when the University took title to the field in 1946. While the deed stated ". . . that the entire landing area . . . shall be maintained at all times in good and serviceable condition . . .", no standards or procedures were prescribed for judging what would be considered "good and serviceable condition".

Report P-5 outlines the periodic surveys and procedures developed for maintaining a continuous record of pavement condition. Prior to resurfacing, structural continuity as measured by pavement cracking in terms of the continuity ratio was the basic measure of pavement condition. Pavement roughness was not a serious problem in the airfield pavement and was not recorded during this period. Joint and crack filling and occasional slab replacement constituted the major part of the maintenance program and the pavement was never allowed to reach a state of disrepair. As the cracking pattern became more advanced, this type of maintenance became prohibitive and bituminous resurfacing was adopted on an annual incremental program.

After resurfacing and with availability of equipment to record pavement profiles and the roughness index, the measure of pavement condition was shifted to cumulative change in roughness, supplemented by visual surveys of reflected cracking. Resealing of the bituminous surfaces before reflected cracking reached an advanced stage was the adopted practice, making timely maintenance the keynote of the program.

From the standpoint of the Michigan study and accumulating experience, it appears desirable to retain both the roughness index and the continuity ratio or its equivalent in evaluating pavement performance, with particular reference to pavement maintenance. Several other examples may be cited from the data being submitted with this final report which indicate that needed maintenance may frequently be reflected in structural deterioration of the surface well in advance of loss in riding quality. In this connection, it may be noted in Appendix A of Report No. P-6 that fairly substantial amounts of cracking, patching, and rutting have an almost negligible effect in the computation of the Present Serviceability Index.

The next example of surface deterioration which may be cited as indicating a possible need for early maintenance is given in Departmental Reports No. D-13 and D-14. The project involved is the previously discussed heavy duty flexible pavement on US-31, the Muskegon - Grand Haven Expressway, which has been given intensive study from the standpoint of pavement performance. While it has retained excellent riding quality, there have been areas of a peculiar type of longitudinal cracking, the cause of which has not been definitely determined. If this type of cracking persists, early sealing may be necessary to protect the surface even though the cracking has had no effect as yet on pavement roughness.

Another interesting example that has been studied is discussed in Departmental Report No. D-10. In this case, a recently built reinforced concrete pavement on I-96 Expressway from Brighton to Novi has been subjected to a concentration of heavily loaded gravel trucks traveling east from the Green Oak Plant of the American Aggregates Corporation, toward Detroit. There has been no more than a normal increase in pavement roughness due to environmental factors or construction conditions, and none which can be identified as due to repetition of heavy loading. In fact, the westbound traffic lane, which carries only normal traffic, and both eastbound and westbound passing lanes have roughness index values as great as or greater than the eastbound traffic lane.

However, this pavement does show signs of more than normal cracking and structural deterioration and there have been some slab replacements not expected in a pavement no more than five years old. Field investigation has not been carried far enough to identify the cause or causes of this early structural deterioration and there is some evidence indicating that the unusual concentration of heavy loading is a contributing factor. Regardless of the factors associated with the performance of this pavement, the purpose of discussing it in this summary is to point it out as another example that timely maintenance may require condition surveys that evaluate the structural behavior of pavements before the loss of structural continuity can be reflected in loss of riding quality.

The Value of Pavement Performance Data to Operations

In the introductory discussion of the utilization of pavement profile data, the operation of the state highway system as a public facility was set forth as one of the four major functions of a state highway department. While this may be recognized by highway engineers and administrators, it does not appear to have been given sufficient emphasis as a separate phase of highway responsibility to gain it the public attention its importance deserves. Pavement performance and pavement profile data have to do specifically with the pavement surface itself, the sole purpose of which is to provide superior riding quality for the comfort, convenience, and economic benefit of the highway user.

The Michigan Pavement Performance Study as organized and operated during the five-year period covered by this review provides an excellent example of the value of accurate pavement evaluation in the operation of the highway network to obtain the maximum economic benefit as a state-wide transportation facility. One of the major objectives of the sponsors of this project was to provide all season operation for full legal axle loads and demonstrate the practicability of such operation by carefully controlled observations of pavement performance.

The first step in this program was the selection of a network of highways on which the spring load limitations could safely be eliminated and then to expand that network as rapidly as possible. Since 1940, Michigan's design standards for trunk line construction have been gauged to provide all year service for legal axle loads, without spring load limitation. Consequently, by 1958, a substantial mileage of such roads had been built. The first pavement evaluation, of January 1, 1958, shown in Fig. 1 of Report P-1, was prepared as a state-wide evaluation of the trunk line system from the standpoint of adequacy to carry legal axle loads without restriction. It included those roads on natural granular subgrades and with natural conditions making them adequate for year-round service (Class 1), and those roads which had been improved with drainage and granular subbases to compensate for seasonal loss of strength (Class 2).

The first pavement evaluation, of 1958, provided an integrated inventory of adequate roads which classified approximately 55 per cent of the state trunk line system as adequate for legal axle loads at all times. Based on this evaluation, the first so-called "frost-free" network was established and public notice given of the raising of spring load restrictions on this network as of January 1, 1958. Including additions made as the result of special studies, the unrestricted network during the 1958 "spring breakup" consisted of some 4545 miles, or about 50 per cent of the state trunk line mileage. Judged in terms of public benefit, it was estimated that the cost of spring load restrictions to the state's industry and agriculture was some $20,000,000 a year, of which a substantial part has been saved during the spring season each year since 1958, without significant damage to the roads.

The second phase of the pavement evaluation was the expansion of the unrestricted network as the result of new construction, betterment, and reclassification. The pavement profile surveys entered directly into the reclassification and provided the supporting data to demonstrate that Michigan design standards did provide roads that would not be damaged by legal axle loads under year-round operation. Under this controlled operation of the state trunk line system, the unrestricted mileage had been increased to 6240, or about two-thirds of the total trunk line mileage, by 1960, when the "Second Pavement Evaluation of 1960" was compiled (Fig. 3, Report P-3). Since 1960, the Department has continued the upgrading of the trunk line system by continued replacement of inadequate roads and some reclassification, for which pavement profile surveys provide part of the data. The "Third Pavement Evaluation" was made as of January 1, 1961. This was the last published map presenting the classification of the complete state trunk line system with respect to adequacy for carrying legal axle loads. Other revisions were made as of January 1, 1962, for use by the Department but this particular map was not published.

Based on the state-wide pavement evaluation, two maps are prepared and issued annually, particularly for the guidance of commercial transportation. These maps are the "All Season Trunkline Highways" and the "Truck Operators' Map". The expansion of the "All Season Trunkline Highways" is graphically illustrated by the annual maps that are issued, which are listed below with references and the consistently increasing mileage in the unrestricted classifications given in the following tabulation.

ALL SEASON TRUNKLINE HIGHWAYS

Date	Length Miles	Length Per Cent	Reference
1 Jan 58	4545	49	Fig. 2, Report P-1
1 Jan 59	5519	59	Files Only
1 Jan 60	5985	64	Fig. 3, Report P-3
1 Jan 61	6344	68	Files Only
1 Jan 62	7031	76	Files Only
1 Jan 63	7455	81	Fig. 1

The mileage of unrestricted highways reported in the above table was the subject of Supplementary Report S-7, at which time revisions were made to eliminate duplication resulting from overlapping trunk line routes. Consequently, this mileage may not agree with mileage previously given in Reports P-1 and P-3. In Figs. 1 and 2 of this report are reproduced the latest maps, published in January, 1963. Full scale copies of the two maps have been inserted in a limited number of copies for official distribution. The map of "All Season Trunkline Highways", Fig. 1, designates the network over which full legal axle loads may be operated at all times. The "Truck Operators' Map", Fig. 2, shows a network of highways calculated to provide continuous routes leading to any destination in the state. Not all of these routes are unrestricted in the spring of the year, thus the operators must use the "All Season" map to check loadings.

The "Truck Operators' Map" also shows "Special Tandem Routes" on which a maximum load of 32,000 pounds on one set of tandem axles or 16,000 pounds per axle is permitted. This loading applies when load restrictions are not in force, including the "All Season" highways at all times. When restrictions are in force, all tandem axles are limited to 26,000 pounds or 13,000 pounds on each axle.

The publication in January of each year of these two maps represents a permit to truck operators and all other highway users for unrestricted use of the designated routes under the authority of the Michigan State Highway Department. They represent the ultimate result of pavement evaluation of state trunk lines in the operation of the state highway system as a transportation facility. What this means in terms of savings to state industry and agriculture has been pointed out and has been cited here to illustrate the importance of well-informed operation of a state highway system and the value of pavement performance data in the support of that type of operation.

SPECIAL STUDIES

One section of the final report was to have been devoted to the special studies which are listed on the first page of Appendix A under nine different headings. The first subject, Study A, was to be the gathering of profile data from 14 projects selected by O. L. Stokstad for special observation. Some field surveys were made on all of these projects, but opportunity was not available to carry on these observations over a sufficiently long period of time to obtain conclusive results. Available data have been reported in the Pavement Profile Summaries and in some cases analyses have been made and results presented in Departmental Reports as shown in Appendix A. As noted in most of these reports, the results are generally considered to be rather fragmentary as it was contemplated that these projects would have to be observed over longer periods of time before final conclusions could be drawn.

Study B was directed to gathering and analyzing data on the temporary displacement at joints due to curling and warping resulting from frost action or temperature differentials. The study originated from inquiries concerning the magnitude and source of temporary roughness developing in the winter on both recently built concrete pavements and old concrete pavements that had been resurfaced. In the case of the latter, particular attention was to be given to the question of the extent to which deformations from the old concrete slab were reflected through the bituminous resurfacing. Attention was focused on certain sections of old US-12 (I-94) west of Ann Arbor and on sections of the Detroit Industrial Expressway in the vicinity of Willow Run where certain special conditions made these projects of special interest. Departmental Report No. D-17 presents some early results on the latter project; these results are only indicative, but they do not appear to support the hope that these pavements had become stress-conditioned in service and after resurfacing would retain their good riding quality for extended periods of time.

The next four Special Studies, C, D, E, and F, are covered by the indicated Departmental Reports, which will be summarized most briefly in this review.

C - Report D-14 - Load-Deflection Observations

Load-deflection measurements on a comprehensive scale by use of the Benkelman beam were first undertaken on M-55, west of Tawas City, in 1960 and were later extended to other projects as a supplement to other pavement profile data. M-55 was a road known to be deficient in load carrying capacity. The pavement deflection tests, under an 18,000 pound axle load, were conducted at different seasons both before and after reconstruction to establish the range of pavement deflection characteristic of inadequate and adequate capacity. The results indicated a direct correlation between pavement deflection and the roughness index, but the significance of this correlation had not been clearly established at the time these observations were discontinued. Continued study of pavement deflection measurements is considered necessary before the present procedures are accepted as a reliable measure of pavement strength over a period of many years. Elastic deflection alone, unrelated to the type of deformation, age of the pavement, and seasonal change, seems to be an incomplete basis for pavement evaluation. Present procedures which ignore permanent deformation and fail to consider the different types of permanent deformation are questioned as being a reliable and generally applicable measure of pavement behavior.

D - Report D-16 - Feasibility Study of Equipment for Recording Continuous Load-Deflection Profiles

The increasing interest in load-deflection measurements in connection with pavement evaluation has stimulated development of methods and equipment for obtaining more reliable data and making more comprehensive observations. The obvious advantages of a continuous load-deflection profile over spot tests led to a well-intended effort to design such equipment, with the full intention of building it if its feasibility could be demonstrated. Three engineering organizations who specialized in the design of measuring and recording equipment and complex instrumentation were retained to make feasibility studies. Report D-14 is a summary of these studies; Appendices B, C, and D of D-14 are the reports of these three organizations, namely: Special Projects Group, University of Michigan Institute of Science and Technology; Strand Engineering Company; and Kearns and Law, Engineers.

These reports will not be reviewed here; those seeking more details on suggested procedures and equipment are referred to the reports themselves. Kearns and Law made the most complete study and carried the design of equipment the furthest. The objective in all cases was to record continuous pavement profiles in the unloaded and loaded conditions superimposed on each other so that the differential deflection could be reliably measured to ±0.002 inch. The conditions under which the measurements were to be made and the specified accuracy imposed such severe requirements that the equipment became so complex and the cost such that the project was considered impracticable, at least at the present time. Preliminary estimates of cost varied from $223,000 to $300,000, and previous experience with preliminary estimates on this type of development would indicate that they are usually low rather than high. Kearns and Law carried their equipment design to the most advanced stage; the schematic design at the end of their report (Appendix C of Report D-14) gives some idea of what could be involved.

E - Report D-18 - True Profile by Means of Digital Computer

It has been recognized for some time that the truck-mounted profilometer or any other equipment of this type that records deviations of a pavement surface from a datum such as a 30-foot floating base line has certain limitations. For example, if such a recording device were run over a pavement profile consisting of a regular sine wave of 30-foot wave length, the cumulative vertical displacement recorded would be double its actual value. Similarly, a pavement surface configuration consisting of 15-foot waves would produce a cumulative vertical displacement or roughness index of zero.

In actual pavement profiles containing compensating randomization (in other words, an equal number of both 15-foot and 30-foot wave lengths), such errors would be balanced in terms of the numerical value of the roughness index but there could still be distortion in the recorded profile. While these limitations do not destroy the value of comparative pavement profiles taken with the same equipment on the same pavement, they do introduce serious experimental error in projects with a predominance of irregularities or deviations of a specific length.

There are two general approaches to eliminating or minimizing this type of experimental error. Profiling equipment can be designed to avoid these errors to varying degrees and some such equipment has been built. A second method is to record the pavement profiles with available equipment (for example, profilometers such as Michigan has used) and then set up a computer program to eliminate or compensate for these errors.

Report D-18 outlines briefly a special study in progress at the time the Michigan Pavement Performance Study was terminated, the objective of which was to set up a computer program to obtain a true profile from that recorded by the profilometers with a 30-foot base line or reference length.

Such a program is predicated on the fact that the pavement profile now recorded can be computed from elevations taken along the pavement wheel path at specified intervals. It follows then that elevations at specified intervals along the pavement can be deduced from a recorded profile. Once the elevations of the pavement at a line of control points are available, a true profile can be computed with respect to any base line length or any desired reference plane or surface. The most useful control or reference datum with respect to which pavement deviations could be measured would be the plan grade to which the pavement was presumably built. If "as-built" plans or grades are not available, measured elevations at a relatively small number of points may be introduced into the program to reproduce a profile with deviations or roughness with respect to the average line of travel that a vehicle traveling the road would follow. This endeavor had reached a stage at which it seemed certain that the necessary program could be developed but the work was not completed. It is being continued by Mr. G. Ragnar Ingimarsson as a part of his doctoral thesis research.

F - Report D-19 - Equipment Operating Manuals

During the building of the truck-mounted profilometer, no complete set of plans was ever drawn and many modifications in measuring and recording equipment have been made from time to time. On several occasions during the past five years, some time has been devoted to bringing together a complete set of drawings giving the details of the equipment. The obvious need for such information led to a concentrated effort to complete this work and the result is presented in Report D-19 as a "Manual for Operating and Servicing the Truck-Mounted Profilometer". This was one of the final assignments to be completed as a Special Study and is intended to facilitate the future use of this equipment.

PAVEMENT PERFORMANCE IN MICHIGAN AS AFFECTED BY STEEL REINFORCING AND SAND SUBBASES

Three "Special Studies", listed as G, H, and I on the first page of Appendix A, have by force of circumstances become so closely related that they will be discussed together in this review. They include the correlation of AASHO Road Test procedures with Michigan pavement design and performance criteria, comparative performance of plain and reinforced concrete pavements, and the role of granular subbases in Michigan pavement construction. Taken together, these three phases of pavement research deal with the most important factors in Michigan pavement design, the evaluation of which is the primary objective of the Michigan Pavement Performance Study. Steel reinforcing to provide structural continuity and granular subbases to compensate for soils of high susceptibility to moisture and frost action are the cardinal features of Michigan design standards.

Both of these features have been incorporated in concrete pavement construction for some years and it is believed that the State's design engineers would strongly support the contention that these two features are the major contributing factors in successful performance of concrete pavements in Michigan. By successful performance, reference is made to the pavement profile surveys presented in Reports P-4 and P-6 and the fact that several thousand miles of Class 1 and Class 2 concrete pavements show no measurable or significant damage attributable to axle loadings up to legal limits and over service periods up to 30 years. On the other hand, there is definite evidence to show that unreinforced concrete pavements and pavements without granular subbases where these features would now be required have suffered measurably from these deficiencies in a manner that appears to correlate directly with traffic or load repetition.

Michigan Roughness Index and AASHO Present Serviceability Index

As cited on Pages 19 and 20 of this summary, the Michigan Roughness Index can be readily correlated with the AASHO Present Serviceability Index and vice versa. This correlation was worked out in some detail in Report P-6.

In addition, some attention was given to analysis of AASHO Road Test results, with particular reference to the value of steel reinforcement and subbases under concrete pavements. Inasmuch as these studies were incomplete at the time that the five year program was terminated, the present report was limited to presenting the results of the Michigan Pavement Performance Study.

Michigan Roughness Data

There are some data from the Michigan Pavement Performance Study on resurfaced concrete pavements which provide a comparison between reinforced and nonreinforced pavement over long periods of time. From the combined data on both reinforced and nonreinforced pavements (see Report P-6, Fig. 18, Page 22), it was observed that bituminous surfaces over plain concrete pavements were generally rougher than those over comparable reinforced concrete slabs.

Roughness of Bituminous Overlays: A further analysis of these data has been made and the results are shown in Figs. 3 and 4. In both cases, the roughness index has been plotted against age or years in service of both the bituminous surface and the underlying concrete slab. Fig. 3 shows the data for the recapped reinforced concrete slabs taken from 59 contracts covering 194 lane miles of pavement with an average life of 24 years. In Fig. 4 are shown the data from recapped plain concrete slabs from 63 contracts and 243 lane miles of pavement with an average life of 32 years.

While both types of recapped pavement are represented by fair size samples, it may not be enough over a spread of 20 years to establish a reliable measure of the rate of increasing roughness. For this reason, comparisons between plain and reinforced concrete slabs which have been resurfaced will be made using the bands of normal performance established for Class 1 and Class 2 rigid pavements as a frame of reference. This band of normal performance has been shown in Figs. 3 and 4 with intercepts on the horizontal axis at roughness index values of 30, 65, and 105, respectively, for the lower limit, average, and upper limit of normal performance. The slope of these lines or the rate of cumulative roughness is 4.5 inches per mile per year for Class 1 and Class 2 pavements.

Most of the plain concrete pavements, built more than 25 years ago, have been retired from service; only a remnant of this type of pavement is still in service after having been resurfaced. This group of projects has thus been selected by natural conditions which made possible their survival; therefore, they must represent the maximum of serviceability in plain concrete under Michigan environment with all contributing factors included. The reinforced concrete, on the other hand, includes those projects which have been resurfaced comparatively early in their service life. These projects have been segregated by natural conditions, from the total mileage of reinforced pavement built, as those most vulnerable to the deteriorating effects of service and environment.

In the first comparisons to be made, in Figs. 3 and 4, age in service is measured from the date of the last resurfacing, some of the older projects having been resurfaced twice and in a few cases three times.

The average roughness index of overlays over the reinforced slabs is 77 inches per mile as compared to 103 inches per mile for nonreinforced slabs.

In Fig. 3, for reinforced slabs, the line showing the average cumulative roughness is offset below that for rigid pavements, indicating better performance than that of Class 1 and Class 2 pavements; the rate of increase is 4.5 inches per mile per year, approximately the same as for the rigid pavements. In contrast, the line showing average performance of overlays over the nonreinforced slabs, in Fig. 4, is offset above that being used as a standard and the slope of the line is 5 inches per mile per year, indicating performance somewhat poorer than that of the Class 1 and Class 2 rigid pavements.

Another indication of pavement performance from the data shown in Figs. 3 and 4 can be found in the number of projects or plotted points in each case that fall above or below the band of normal performance. Thus, in Fig. 3, for the reinforced concrete, there are quite a number of projects showing better than normal performance and only a few rougher than normal. In Fig. 4, for the plain concrete slabs, the situation is reversed, with a larger group of projects much rougher than normal and fewer that are better than normal.

In Figs. 3 and 4, the roughness index values of the overlays have also been plotted against the age of the underlying concrete slab in the upper group of points. This has been done to show the age of the underlying concrete slabs as compared to the length of service since the last resurfacing, as well as to provide another basis of comparison between reinforced and nonreinforced concrete pavements. The age of the concrete slab is a special condition to be noted in such a comparison, as this will modify the relationship between roughness and age in service. The reinforced concrete slabs vary in age from 10 to 35 years with an average life of 24 years, while the plain concrete slabs range from 24 to 40 years with an average life of 32 years.

Thus, the normal relationship between roughness and age in service may be changed by the sequence of events in the pavement life. While this particular group of projects has been subjected to special conditions, there may still be a significant comparison in terms of the cumulative increase in roughness. In Figs. 3 and 4 this has been shown, with reference to the age of the underlying slab, as the slope of a straight line through the average points for each five year period. Thus, in Figs. 3 and 4, the average rates of increase or cumulative roughness are 2 and 4 inches per mile per year, respectively, for the reinforced and nonreinforced concrete when referred to the age of the underlying slab.

Effect of Steel Reinforcing: In summarizing the performance of bituminous surfaced concrete slabs, the data in Figs. 3 and 4 show that the pavements with steel reinforcing are measurably smoother, thus demonstrating that they retain their riding quality longer than the plain concrete.

These findings confirm results of earlier pavement surveys in Michigan reported in references cited on Page 2 of this summary, in which it was found that pavements with steel reinforcement were measurably smoother and had measurably less cracking than did unreinforced pavements (See Report P-1, Page 2).

Effect of Subbases on Pavement Performance

The function of a subbase is to neutralize or compensate for the loss of subgrade support in fine-grained soils susceptible to loss of strength or disintegration in the presence of water. In poorly constructed pavements, the most aggravated type of loss in subgrade support is pumping, which may occur in the original subgrade soil or in the material introduced as a subbase. The factors which produce pumping in concrete pavements are so well known that there should be no need to recite them.

In order to perform their function, subbases for concrete pavements must be constructed of materials which in themselves do not pump and they must be thick enough to protect the subgrade from pumping and from stress concentration greater than its decreased strength. Michigan has met this problem on its Class 2 roads by the use of free-draining granular base courses because of the availability of such material in the state. California, on the other hand, used cement-treated bases which have accomplished the same objective in a different way.

Michigan's granular subbases combine texture and drainability in order to function effectively. Either the material must be coarse enough to not pump in the presence of water, be porous enough to permit the water to drain out, or provide the optimum combination of these characteristics. In order to drain, an outlet must be made available and the base must be thick enough to provide the required gradient for water to move from the center of the roadway to the side ditches. These are not very profound statements of the physical laws which control the movement of water through porous media, but they are the practical requirements to prevent pumping which must be provided.

Michigan practice has been developed over a period of years during which subbase thickness has been adjusted by experience to compensate for variation in available materials. Evidence that it has been successful has been gathered in the Michigan Pavement Performance Study. The fact that many miles of Class 2 concrete pavement have exhibited performance equal to or better than that of the Class 1 pavements on well-drained natural granular subgrades is the major test. The bulk of these performance records have been presented in Report P-4 in terms of a compilation of cumulative roughness on both classes of pavement. A number of specific examples of both good and bad performance produced by improved and unimproved subgrades are contained in the series of reports, P-1 to P-6. This evidence stands as the result of "established practice" in Michigan which has been successful over a sufficient period of time and variety of natural environmental conditions that it is hard to see how its validity could be denied.

CONCLUSION

Termination, on December 31, 1962, of the last of a series of annual contracts with the Michigan Highway Planning Survey marked the end of a five year program of the Michigan Pavement Performance Study. After five years of field surveys of existing pavement in service, providing 10,000 lane miles of pavement profile, it has been a difficult task to assemble and present the results of such a large volume of data in usable form. This "Five Year Summary" has been prepared as an index to these data and a summary of the findings. In conclusion, it is even more difficult but necessary to restate in concise form the principal conclusions drawn from the study, as follows:

1. Pavement performance has been evaluated in terms of two basic measures of the physical condition of the pavement defined as the roughness index and the continuity ratio. Both of these quantities are required to evaluate the pavement condition at any given time. The roughness index, in conjunction with the recorded pavement profile, measures the riding quality or serviceability of the pavement; the pavement profile supplies an insight into the source of the progressive changes which have taken place during the life of the pavement. The continuity ratio expresses in quantitative terms the structural continuity of the slab and enables one to anticipate its ability to continue in service

without excessive deterioration due to load application. It indicates the need for maintenance or improvements to forestall excessive loss of riding quality.

2. The data compilations made a part of the final summary have been listed in the table of contents and described in more detail in the section of the text on "Use of Pavement Profile Summaries" (Pages 4 through 7). The large mileage of recorded pavement profile and supplementary data constitute an accurate and realistic pavement inventory, the value of which has been only partially utilized to date. Its full value to design and construction practice and in the operation of the state highway system as a transportation facility can be realized only by its continued use and by keeping it up-to-date and growing as the highway system grows.

3. Michigan's current design standards for rigid, Portland cement concrete pavements are adequate for legal axle loads, providing all-season service without load restriction. This conclusion is supported by the fact that pavement profile surveys of thousands of miles of such pavement on natural or modified subgrades meeting those standards showed no significant loss of riding quality due to unlimited load application over service periods up to thirty years.

4. Somewhat in contrast, these surveys provided evidence that concrete pavements deteriorate due to environmental and climatic influence, losing riding quality in terms of roughness at an average rate of 4 to 5 inches per mile per year. Assuming a roughness index of 200 to 250 inches per mile as the limit of acceptable riding quality, an initial roughness index of 50 would set the useful pavement life at 30 to 40 years until resurfacing or reconstruction would be required.

5. Flexible pavements with bituminous surfaces built to equivalent all-season standards show comparable performance. Such flexible pavements also suffer a cumulative loss of riding quality of comparable magnitude even though the mechanics of a flexible pavement produce a quite different relation between cause and effect. Conclusions concerning the performance of flexible pavements must be qualified in the Michigan study by the fact that present profile data are limited both in mileage and periods of service.

6. With full realization that pavement life and serviceability are controlled more by environmental effects than by load application, pavement design practice may be pointed in the future more directly toward compensating for these natural destructive influences. The range of pavement performance covered by the present profile surveys is sufficiently large and the contrast between the best and poorest performance such as to indicate that emphasis in design on these environmental factors may produce substantial improvements.

7. Pavement profile data have produced much evidence that pavement construction practice can be improved by more attention to riding quality produced and to those questionable practices which are the primary source of poor riding quality. Initial roughness built into the pavement presently takes up too much of the range available to absorb the cumulative roughness over the years, which may be reflected directly in a reduced useful life of a pavement.

8. Pavement profile surveys and the two factors for evaluating pavement condition, the roughness index and the continuity ratio, provide reliable and accurate criteria for gauging serviceability and determining when and what maintenance should be provided. To perform this function effectively, profile data as a pavement inventory should be kept up-to-date and these records made readily available to the Department. The development of cracking, as a measure of structural continuity, and other direct evidence of structural deterioration are necessary and timely indications of needed maintenance which anticipate loss of riding quality.

9. A complete and accurate inventory of the state highway system has direct value in several ways in the operation of the highway system as a transportation facility. It provides a factual basis for eliminating unnecessary restrictions on the use of the highways, with economic benefits exceeding many times the cost of providing and maintaining that inventory. It provides the basis for extending the unrestricted network of state highways and the evidence that determines whether or not the unrestricted use and the continuation of that classification is justified. In this time when pavement design is on trial all over the country, it provides realistic and incontrovertible evidence of the soundness of Michigan design standards and points the way to further improvement in carrying out these standards under varying field conditions.

10. A number of special studies were undertaken and in progress when the five-year program of the Michigan Pavement Performance Study was terminated. Reports on these studies are listed in the Table of Contents and their present status is indicated in Appendix A and in the reports themselves. No attempt will be made to further summarize these special studies beyond calling attention to them. A review of the reports and the discussion of them in the text (Pages 27 through 32) will best determine the value of the work done to date and what might be expected if they are continued.

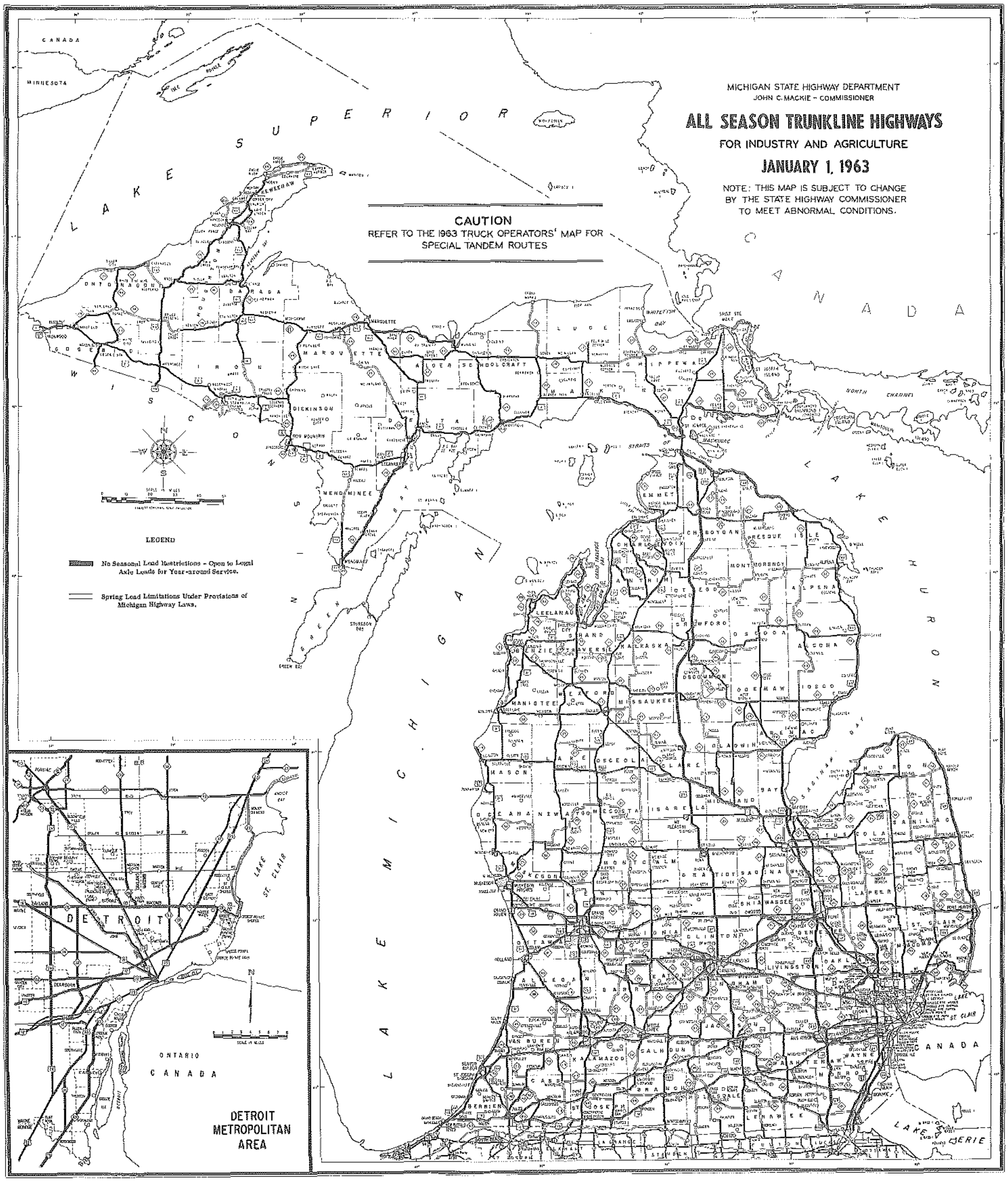

MICHIGAN STATE HIGHWAY DEPARTMENT
JOHN C. MACKIE - COMMISSIONER
ALL SEASON TRUNKLINE HIGHWAYS
FOR INDUSTRY AND AGRICULTURE
JANUARY 1, 1963
NOTE: THIS MAP IS SUBJECT TO CHANGE BY THE STATE HIGHWAY COMMISSIONER TO MEET ABNORMAL CONDITIONS.
CAUTION
REFER TO THE 1963 TRUCK OPERATORS' MAP FOR SPECIAL TANDEM ROUTES
LEGEND
No Seasonal Load Restrictions - Open to Legal Axle Loads for Year-around Service.
Spring Load Limitations Under Provisions of Michigan Highway Laws.
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
CANADA
MINNESOTA
WISCONSIN
GREEN BAY
DETROIT
ONTARIO
CANADA
LAKE ST. CLAIR
DETROIT METROPOLITAN AREA

Fig. 1

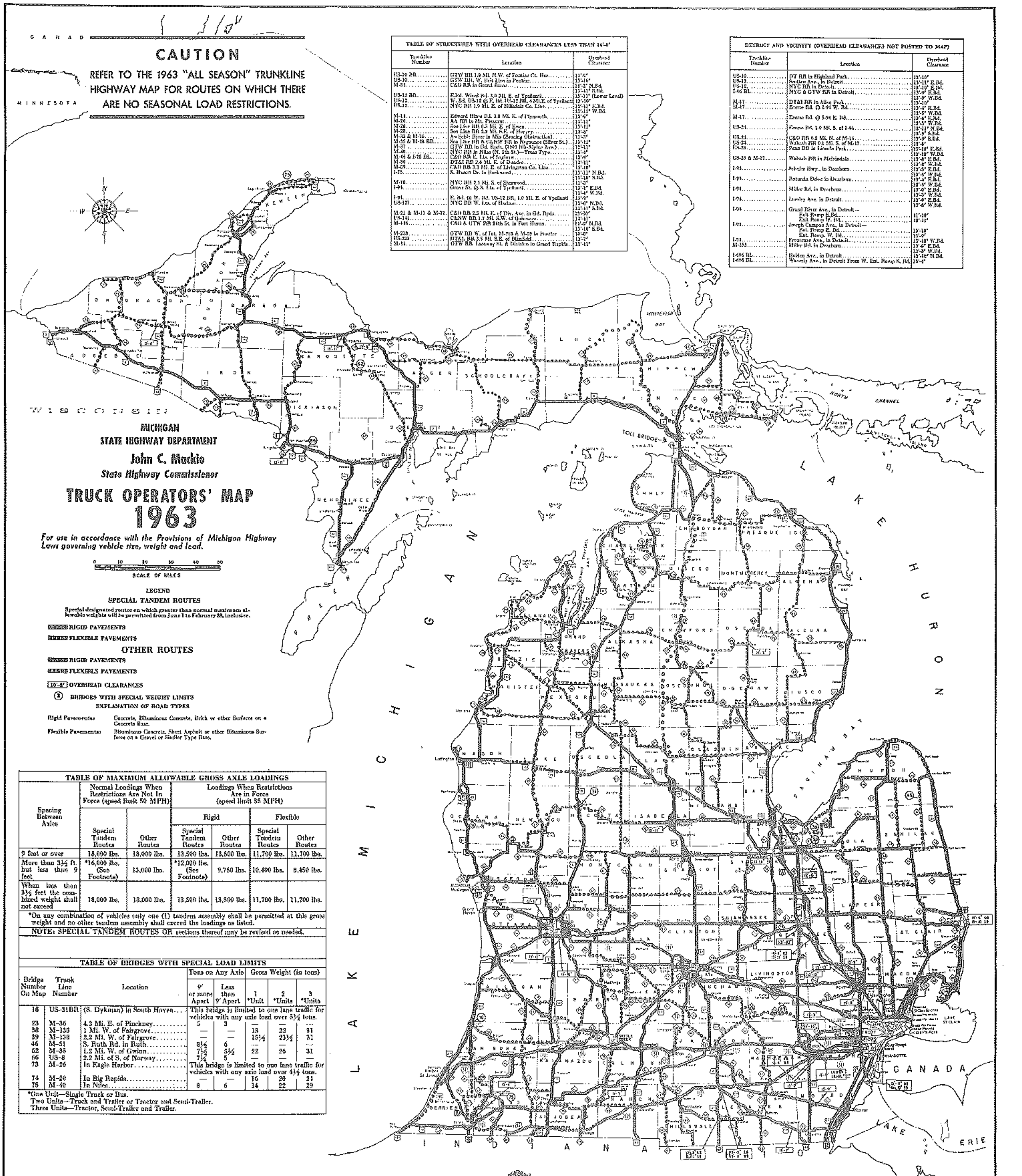


TABLE OF MAXIMUM ALLOWABLE GROSS AXLE LOADINGS

Spacing Between Axles	Normal Loadings When Restrictions Are Not In Force (speed limit 50 MPH)		Loadings When Restrictions Are in Force (speed limit 35 MPH)			
			Rigid		Flexible	
	Special Tandem Routes	Other Routes	Special Tandem Routes	Other Routes	Special Tandem Routes	Other Routes
9 feet or over	18,000 lbs.	18,000 lbs.	13,500 lbs.	13,500 lbs.	11,700 lbs.	11,700 lbs.
More than 3½ ft. but less than 9 feet	*16,000 lbs. (See Footnote)	13,000 lbs.	*12,000 lbs. (See Footnote)	9,750 lbs.	10,400 lbs.	8,450 lbs.
When less than 3½ feet the combined weight shall not exceed	18,000 lbs.	18,000 lbs.	13,500 lbs.	13,500 lbs.	11,700 lbs.	11,700 lbs.

*On any combination of vehicles only one (1) tandem assembly shall be permitted at this gross weight and no other tandem assembly shall exceed the loadings as listed.

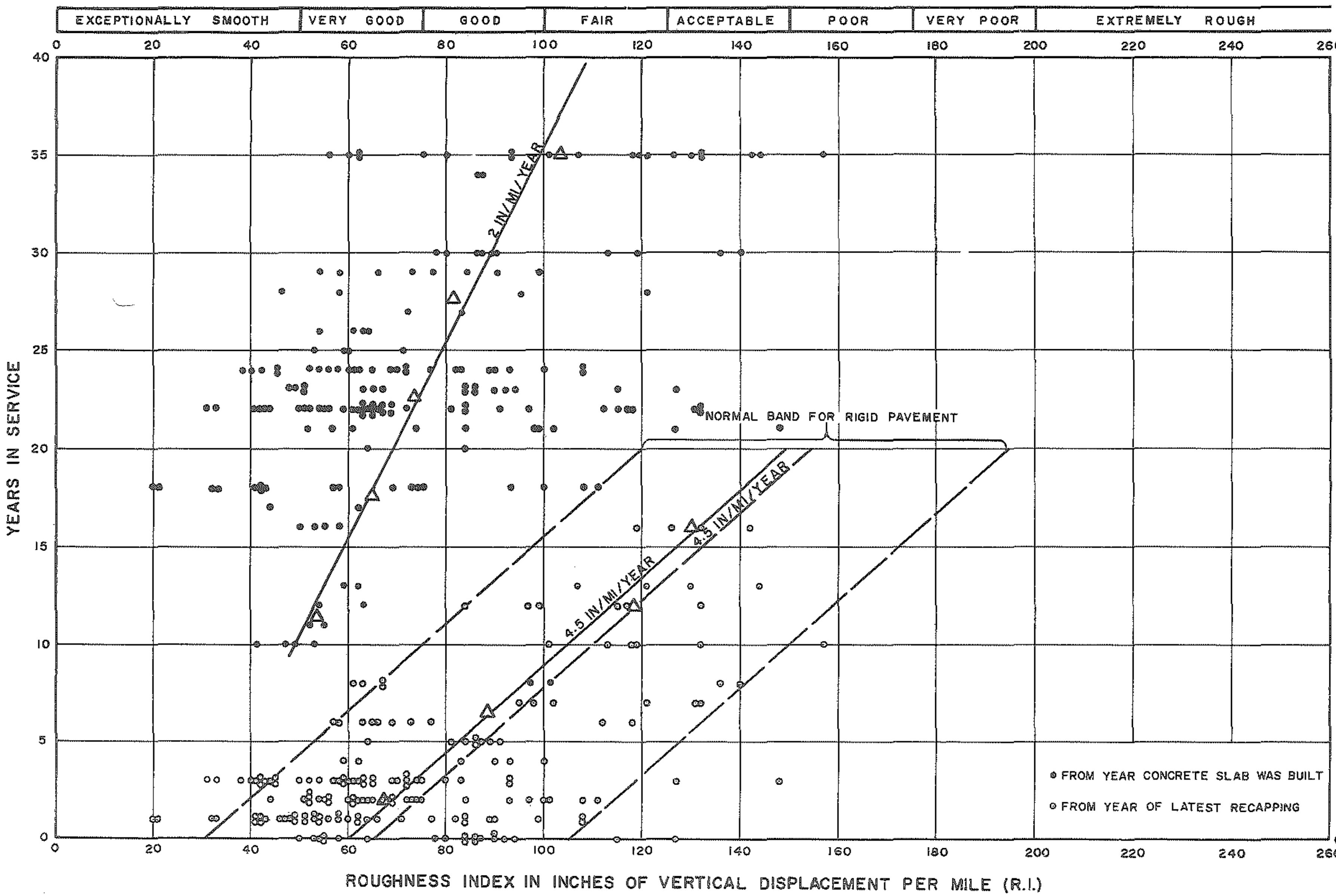
NOTE: SPECIAL TANDEM ROUTES OR sections thereof may be revised as needed.

TABLE OF BRIDGES WITH SPECIAL LOAD LIMITS

Bridge Number On Map	Trunk Line Number	Location	Tons on Any Axle: 9' or more Apart	Tons on Any Axle: Less than 9' Apart	Gross Weight (in tons): 1 *Unit	Gross Weight (in tons): 2 *Units	Gross Weight (in tons): 3 *Units
16	US-31BR	(S. Dykman) in South Haven	This bridge is limited to one lane traffic for vehicles with any axle load over 5½ tons.				
23	M-36	4.3 Mi. E. of Pinckney	5	3	—	—	—
38	M-138	1 Mi. W. of Fairgrove	—	—	13	22	31
39	M-138	2.2 Mi. W. of Fairgrove	—	—	15½	23½	31
46	M-51	S. Ruth Rd. in Ruth	8½	6	—	—	—
62	M-35	1.2 Mi. W. of Gwinn	7½	5½	22	26	31
66	US-8	2.2 Mi. of S. of Norway	7¼	5	—	—	—
73	M-26	In Eagle Harbor	This bridge is limited to one lane traffic for vehicles with any axle load over 4½ tons.				
74	M-20	In Big Rapids	—	—	16	20	24
75	M-40	In Niles	8	6	14	22	29

*One Unit—Single Truck or Bus.
Two Units—Truck and Trailer or Tractor and Semi-Trailer.
Three Units—Tractor, Semi-Trailer and Trailer.

Fig. 2

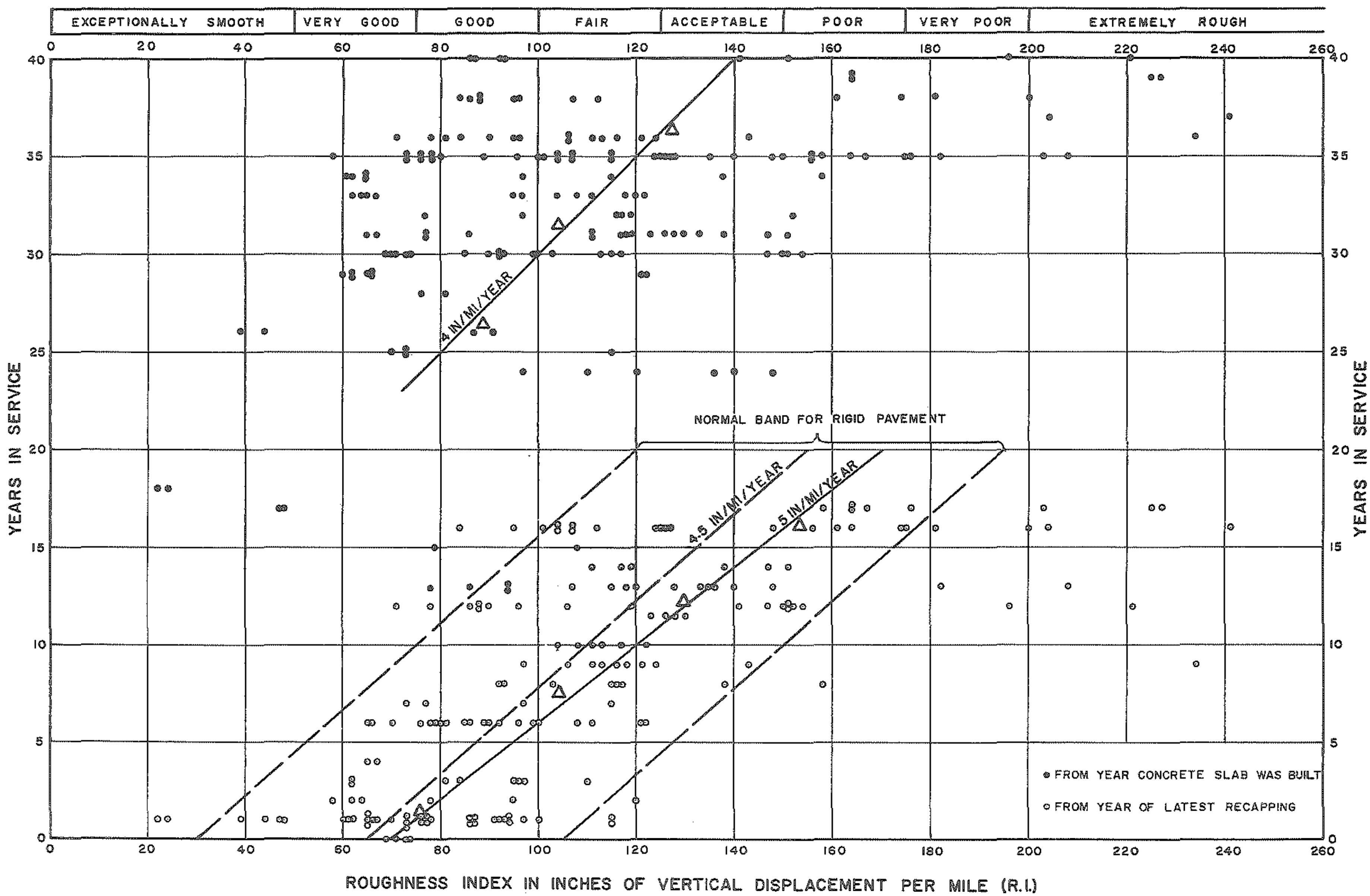


CUMULATIVE ROUGHNESS VS. YEARS IN SERVICE - RECAPPED REINFORCED CONCRETE PAVEMENT

CLASS I TRAFFIC LANE

BASED ON 1958, '59, '60 & '61 SURVEYS

FIG. 3



CUMULATIVE ROUGHNESS VS. YEARS IN SERVICE - RECAPPED NONREINFORCED CONCRETE PAVEMENT

CLASS I TRAFFIC LANE

BASED ON 1958, '59, '60 & '61 SURVEYS

FIG. 4

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

APPENDIX A

SPECIAL STUDIES

Departmental Report Number	Special Studies	Description
	A	Special Projects: 14 Projects Which Include Special Design Features, Selected by O. L. Stokstad (List Attached)
D-17	B	Winter Joint Study: 16 Selected Pavements (List Attached)
D-14	C	Load-Deflection Observations
D-16	D	Feasibility Study of Equipment for Recording Continuous Load-Deflection Profiles
D-18	E	True Profile Computer Program
D-19	F	Equipment Operating Manuals
	G	Correlation of AASHO Road Test Results with Michigan Pavement Design and Performance
	H	Comparative Performance of Plain and Reinforced Concrete Pavement
	I	Role of Granular Subbases in Michigan Pavement Design and Construction

A - SPECIAL PROJECTS

Departmental Report Number	Special Project Number	Description
Flexible Pavement Designs		
D-5, D-13, and D-14	1	US-31, Grand Haven to Muskegon (6 miles) This project was the first of the modern dual roadway expressways built in the state using flexible design. Purpose of a performance study was (1) to study the influence of modern construction techniques on the smoothness and durability of flexible designs and (2) to compare the performance of modern flexible construction with modern rigid pavement construction. The intent was not only to obtain records of pavement smoothness as built, but also to study the influence of time, use, and environment on pavement behavior.
	2	I-96, Coopersville-Nunica to Muskegon (12 miles) This project involves both sandy and clay soils, with the latter including silty frost-heaving materials. This project, therefore, presents opportunities to study the adequacy of undercutting for the control of frost heaving and also to study the adequacy of the 40-inch overall flexible pavement thickness for expressway use.
D-12 and D-14	3	I-94, State Line to Stevensville (24 miles) This project was added to the list of special projects because of its strategic location, the concern

Departmental Report Number	Special Project Number	Description
Flexible Pavement Designs		
		caused by the selection of a flexible design, the heavy traffic to be carried, the aggregate problems which developed, and the combination of poor and good foundation conditions involved. A continuing record of pavement performance of this highway could prove to be of special value.
	4	M-79, West of Charlotte (6 miles) This project was included in the pavement performance study program because it represents modern low cost design of flexible pavement construction for the more lightly travelled trunklines.
D-7 and D-14	5	M-55, Tawas City (6 miles) This project provided an opportunity to study the performance of a weak, failing pavement before reconstruction and then an opportunity to study the adequacy of the reconstruction, consisting of a granular lift with new base and surface.
Rigid Pavement Designs		
	6	I-94, Stevensville to Hartford (24 miles) This pavement was added primarily to combine with Project 3 above, for the purpose of comparing the performance of rigid and flexible pavement designs under similar conditions of soil, climate, and traffic.

Departmental Report Number	Special Project Number	Description
Rigid Pavement Designs		
D-6	7	M-20, Midland to Bay City (12 miles) This pavement and the Grand Haven - Muskegon pavement were built the same summer. Performance surveys were first made to study the "ride character" of two well-built pavements of competitive designs. Periodic performance surveys have been made to study the effect of aging on these rigid and flexible pavement designs.
D-10	8	I-96, Brighton to Novi (12 miles) This project was included to study the effect of an unusual traffic condition. The eastbound roadway is subjected to a steady parade of trucks hauling maximum legal loads from the gravel pit at Green Oaks to Detroit. Pavement performance surveys should demonstrate the character and extent of the influence of such traffic on modern pavement design.
	9	I-94, Detroit Industrial Expressway, Wyoming to Livernois (2 miles) This heavily travelled highway was added because it was felt that any pavement performance study in this state would be incomplete without including a portion of a capacity-taxed big city expressway.
D-15	10	I-75, Detroit-Toledo Expressway, Rockwood to Monroe (12 miles) This is another heavily travelled corridor highway carrying heavy

Departmental Report Number	Special Project Number	Description

Rigid Pavement Designs

Departmental Report Number	Special Project Number	Description
		commercial traffic. It was included in the study to learn more about the long range rate of change in serviceability of a modern design subjected to intensive use and thereby to check the adequacy of present strength design methods.
	11	M-43, Grand Ledge West (6 miles) This project includes a section of plain pavement without steel reinforcement. Soil and foundation conditions are very uniform over the entire length of the road. This project, therefore, offers an excellent opportunity to study the influence of steel reinforcement on pavement performance.
D-20	12	I-96, Portland to M-66 (12 miles) This project involves an experimental section of continuously reinforced Portland cement concrete pavement. Pavement performance records on this project are needed to obtain numerical values for use in comparing continuously reinforced with conventional pavement designs.
	13	I-96, Pine Tree Road East to Ingham-Livingston County Line (12 miles) This project also contains an experimental section of continuously reinforced pavement. Here again, pavement performance records are a necessary part of the study.

Departmental Report Number	Special Project Number	Description

Rigid Pavement Designs

	14	I-75, St. Ignace North (6 miles) This road in northern Michigan encompasses a wide range of foundation conditions in a severe climate. It includes a section of swampy clay so soft that peat swamp type displacement took place below the highway embankment during construction. Pavement performance records would be useful, especially in studying the influence of foundation conditions on pavement service.

B - WINTER JOINT STUDY

Number		Route
1	US-12	Detroit Industrial Expressway
2	I-94	Between Jackson and Chelsea
3	US-112	Ypsilanti to Wayne
4	US-23	M-17 towards Milan
5	US-23	Fenton to Brighton
6	US-112	Ypsilanti to Hillsdale County
7	US-127	US-112 south to Hudson
8	M-50	Jackson to south of US-112
9	M-60	Concord northeast to divided highway
10	US-112	Hillsdale County
11	Old US-12	Detroit Industrial Expressway
12	M-17	Ecorse Road - Denton to Beck Road
W1	27L	Willow Run Airport
W2	TWB	Willow Run Airport
W3	27R	Willow Run Airport
W4	14	Willow Run Airport

SUMMARY OF PAVEMENT SURVEY DATA

SPECIAL PROJECTS

JUNE, 1962 SURVEY

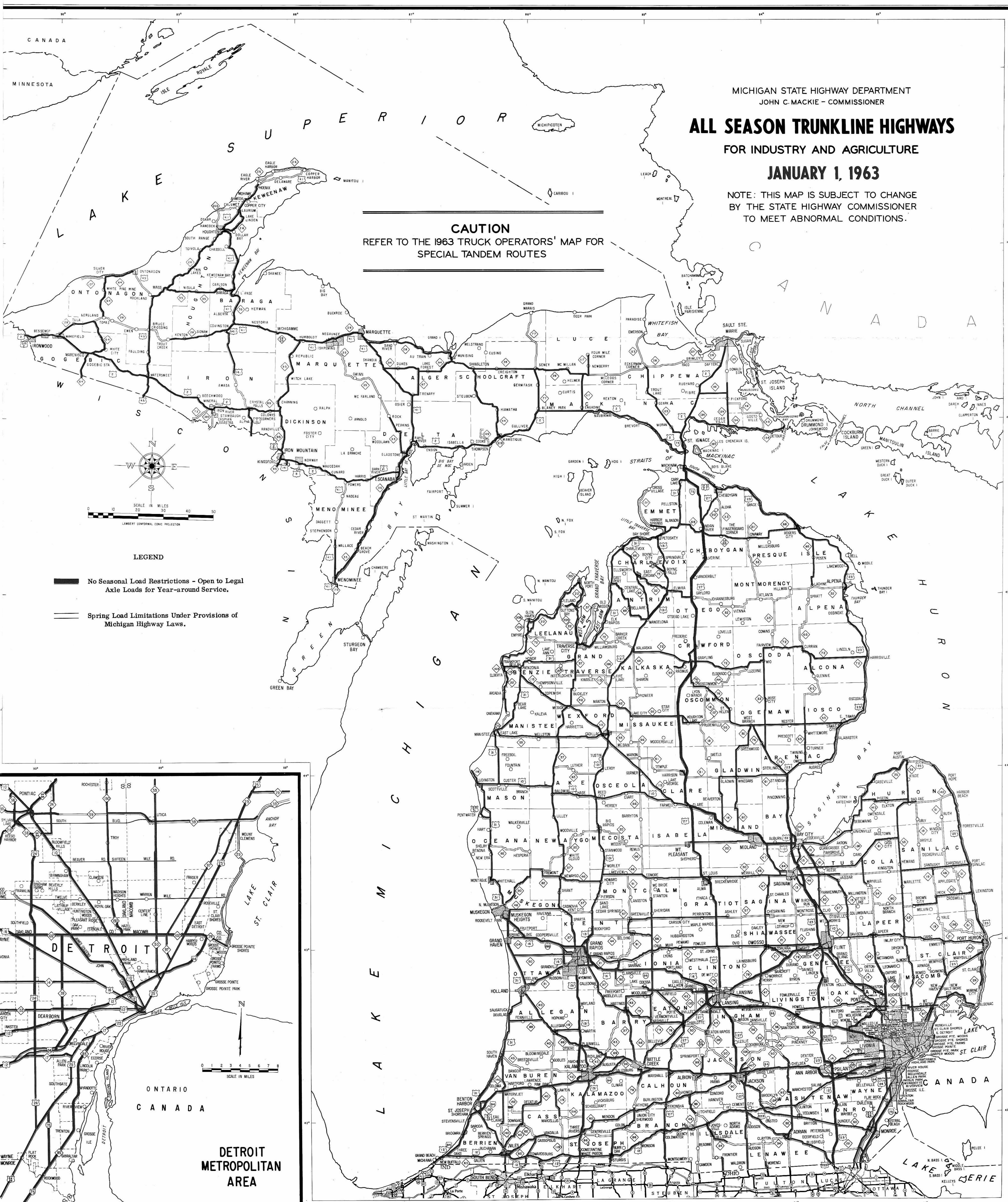
I-75: St. - Ignace - North

SHEET NO:

ROUTE NO.	CONTRACT NO.	PAVEMENT TYPE	YEAR BUILT	DISTRICT AND CONTROL SECTION	ROLL CHART NO.	DATE OF SURVEY	WEATHER	PAVEMENT CONDITION	AIR TEMP. F°	PAVE. TEMP. F°	SUB GRADE TEMP. F°	SURVEYED LENGTH IN MILES	DIRECTION AND LANE NO.	WHEEL PATH	ROUGHNESS INDEX=R.I. INCHES PER MILE AVE.	MIN.	MAX.	CLASS	ORIGINAL CONTINUITY RATIO C.R.o	EXISTING CONTINUITY RATIO C.R.E	CRACKING INDEX C.I. %
I-75	25-C2	Reinforced Concrete	1957	2-49025 Mile 0.0-0.6	1576	6-16-62	Hazy	Dry	72	83	70	0.616	S-1	OWP IWP	169 177	- -	- -	2	6.40	3.33	-
					1578	6-16-62	Cloudy	Dry	75	88	70	0.616	S-2	OWP IWP	140 143	- -	- -	2	6.40	3.28	-
					1577	6-16-62	Hazy	Dry	72	80	70	0.627	N-2	IWP OWP	147 124	- -	- -	2	6.35	3.70	-
					1575	6-12-62	Clear	Dry	74	72	65	0.629	N-1	IWP OWP	121 127	- -	- -	2	6.54	2.14	-
	25-C5	Reinforced Concrete	1960	2-49025 Mile 0.6-1.9	1576	6-16-62	Hazy	Dry	72	81	70	1.253	S-1	OWP IWP	121 110	108 104	156 140	2	5.99	3.64	-
					1578	6-16-62	Cloudy	Dry	74	88	70	1.251	S-2	OWP IWP	118 122	92 104	144 140	2	5.99	4.12	-
					1577	6-16-62	Hazy	Dry	72	80	70	1.213	N-2	IWP OWP	145 130	116 108	192 172	2	5.96	4.31	-
					1575	6-12-62	Clear	Dry	74	73	66	1.211	N-1	IWP OWP	136 127	124 116	176 160	2	6.03	3.83	-
	25-C3	Reinforced Concrete	1960	2-49025 Mile 1.9-4.8	1576	6-16-62	Hazy	Dry	72	79	70	2.882	S-1	OWP IWP	108 102	80 72	140 140	2	6.32	3.70	-
					1578	6-16-62	Cloudy	Dry	74	88	70	2.877	S-2	OWP IWP	108 121	88 80	152 160	2	6.33	3.71	-
					1577	6-16-62	Hazy	Dry	72	80	70	2.901	N-2	IWP OWP	135 120	108 92	204 180	2	6.27	3.41	-
					1575	6-12-62	Clear	Dry	73	75	67	2.899	N-1	IWP OWP	119 119	84 92	176 192	2	6.30	3.68	-
	25-C3	Reinforced Concrete	1957	2-49025 Mile 4.8-3.3	1576	6-16-62	Hazy	Dry	72	77	70	1.444	S-1	OWP IWP	87 74	80 68	92 76	2	6.63	3.70	-
					1578	6-16-62	Cloudy	Dry	74	88	70	1.442	S-2	OWP IWP	79 87	68 80	84 108	2	6.63	3.70	-
					1577	6-16-62	Hazy	Dry	72	80	70	1.442	N-2	IWP OWP	85 79	64 76	116 80	2	6.55	3.41	-
					1575	6-12-62	Cloudy	Dry	73	76	68	1.450	N-1	IWP OWP	83 90	80 84	88 96	2	6.39	2.91	-

O.W.P. = OUTER WHEEL PATH
I.W.P. = INNER WHEEL PATH

APPENDIX B


MICHIGAN STATE HIGHWAY DEPARTMENT
JOHN C. MACKIE - COMMISSIONER
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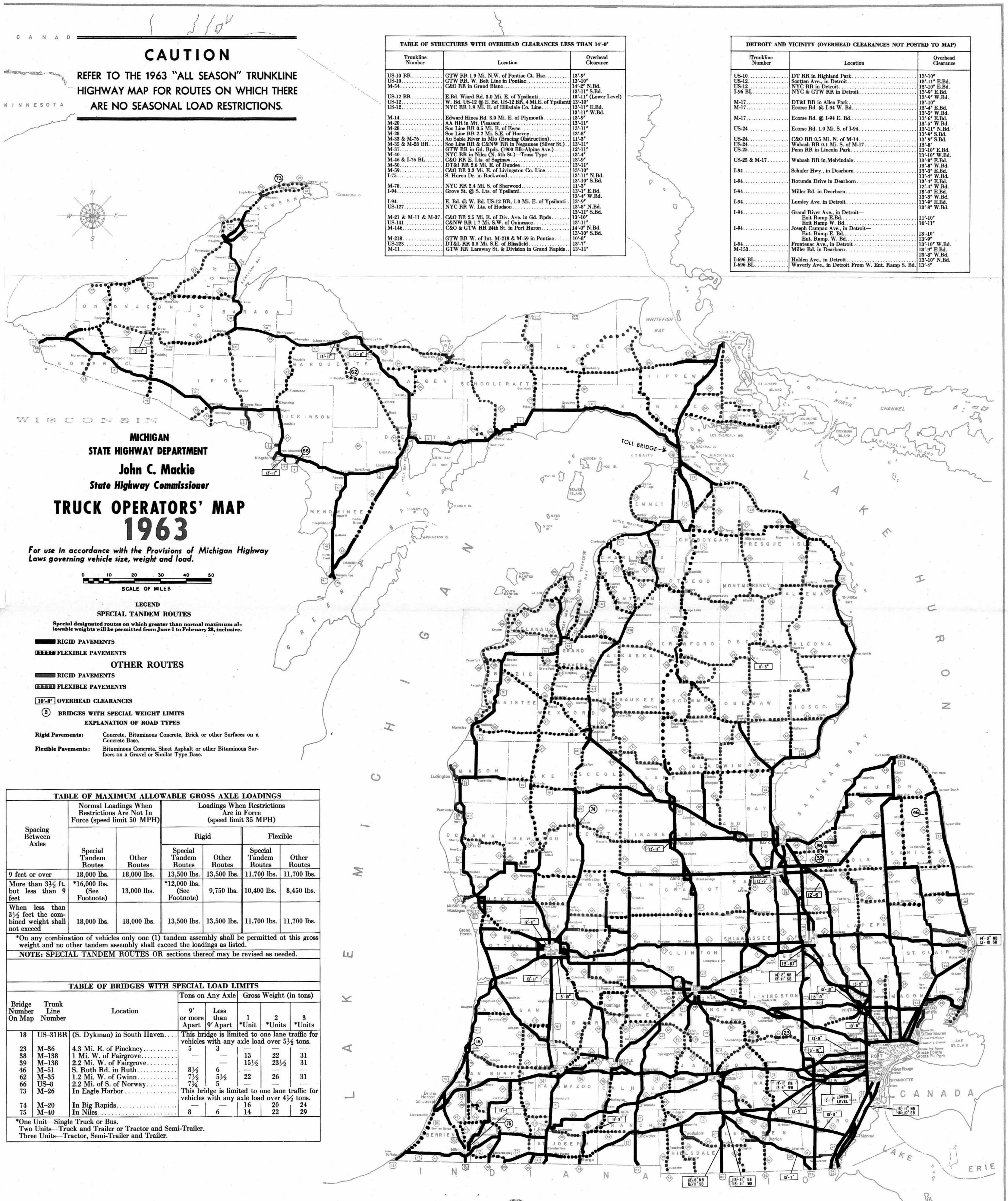
REFER TO THE 1963 TRUCK OPERATORS' MAP FOR SPECIAL TANDEM ROUTES
LEGEND
No Seasonal Load Restrictions - Open to Legal Axle Loads for Year-around Service.
Spring Load Limitations Under Provisions of Michigan Highway Laws.
SCALE IN MILES
LAMBERT CONFORMAL CONIC PROJECTION
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
CANADA
MINNESOTA
WISCONSIN
INDIANA
OHIO
DETROIT METROPOLITAN AREA
ONTARIO CANADA
DETROIT



CAUTION

REFER TO THE 1963 "ALL SEASON" TRUNKLINE HIGHWAY MAP FOR ROUTES ON WHICH THERE ARE NO SEASONAL LOAD RESTRICTIONS.

MICHIGAN
STATE HIGHWAY DEPARTMENT

John C. Mackie
State Highway Commissioner

TRUCK OPERATORS' MAP
1963

For use in accordance with the Provisions of Michigan Highway Laws governing vehicle size, weight and load.

0 10 20 30 40 50
SCALE OF MILES

LEGEND

SPECIAL TANDEM ROUTES

Special designated routes on which greater than normal maximum allowable weights will be permitted from June 1 to February 28, inclusive.

- **RIGID PAVEMENTS**
- **FLEXIBLE PAVEMENTS**

OTHER ROUTES

- **RIGID PAVEMENTS**
- **FLEXIBLE PAVEMENTS**
- 10'-8" **OVERHEAD CLEARANCES**
- (2) **BRIDGES WITH SPECIAL WEIGHT LIMITS**

EXPLANATION OF ROAD TYPES

Rigid Pavements: Concrete, Bituminous Concrete, Brick or other Surfaces on a Concrete Base.

Flexible Pavements: Bituminous Concrete, Sheet Asphalt or other Bituminous Surfaces on a Gravel or Similar Type Base.

TABLE OF STRUCTURES WITH OVERHEAD CLEARANCES LESS THAN 14'-0"

Trunkline Number	Location	Overhead Clearance
US-10 BR	GTW RR 1.9 Mi. N.W. of Pontiac Ct. Hse	13'-9"
US-10	GTW RR, W. Belt Line in Pontiac	13'-10"
M-54	C&O RR in Grand Blanc	14'-2" N.Bd. 13'-11" S.Bd.
US-12 BR	E.Bd. Wiard Rd. 3.0 Mi. E. of Ypsilanti	13'-11" (Lower Level)
US-12	W. Bd. US-12 @ E. Bd. US-12 BR, 4 Mi.E. of Ypsilanti	13'-10"
US-12	NYC RR 1.9 Mi. E. of Hillsdale Co. Line	13'-11" E.Bd. 13'-11" W.Bd.
M-14	Edward Hines Rd. 3.0 Mi. E. of Plymouth	13'-9"
M-20	AA RR in Mt. Pleasant	13'-11"
M-28	Soo Line RR 0.5 Mi. E. of Ewen	13'-11"
M-28	Soo Line RR 2.2 Mi. S.E. of Harvey	13'-8"
M-33 & M-76	Au Sable River in Mio (Bracing Obstruction)	11'-3"
M-35 & M-28 BR	Soo Line RR & C&NW RR in Negaunee (Silver St.)	13'-11"
M-37	GTW RR in Gd. Rpds. (1900 Blk-Alpine Ave.)	12'-11"
M-40	NYC RR in Niles (N. 5th St.)—Truss Type	13'-4"
M-46 & I-75 BL	C&O RR E. Lts. of Saginaw	13'-9"
M-50	DT&I RR 2.6 Mi. E. of Dundee	13'-11"
M-59	C&O RR 3.3 Mi. E. of Livingston Co. Line	13'-10"
I-75	S. Huron Dr. in Rockwood	13'-11" N.Bd. 13'-10" S.Bd.
M-78	NYC RR 2.4 Mi. S. of Sherwood	11'-3"
I-94	Grove St. @ S. Lts. of Ypsilanti	13'-1" E.Bd. 13'-4" W.Bd.
I-94	E. Bd. @ W. Bd. US-12 BR, 1.0 Mi. E. of Ypsilanti	13'-9"
US-127	NYC RR W. Lts. of Hudson	13'-8" N.Bd. 13'-11" S.Bd.
M-21 & M-11 & M-37	C&O RR 2.5 Mi. E. of Div. Ave. in Gd. Rpds	13'-10"
US-141	C&NW RR 1.7 Mi. S.W. of Quinessec	13'-11"
M-146	C&O & GTW RR 24th St. in Port Huron	14'-0" N.Bd. 13'-10" S.Bd.
M-218	GTW RR W. of Int. M-218 & M-59 in Pontiac	10'-8"
US-223	DT&L RR 3.5 Mi. S.E. of Blissfield	13'-7"
M-11	GTW RR Laraway St. & Division in Grand Rapids	13'-11"

DETROIT AND VICINITY (OVERHEAD CLEARANCES NOT POSTED TO MAP)

Trunkline Number	Location	Overhead Clearance
US-10	DT RR in Highland Park	13'-10"
US-12	Scotten Ave., in Detroit	13'-11" E.Bd.
US-12	NYC RR in Detroit	13'-10" E.Bd.
I-96 BL	NYC & GTW RR in Detroit	13'-9" E.Bd. 13'-9" W.Bd.
M-17	DT&I RR in Allen Park	13'-10"
M-17	Ecorse Rd. @ I-94 W. Bd.	13'-4" E.Bd. 13'-5" W.Bd.
M-17	Ecorse Rd. @ I-94 E. Bd.	13'-6" E.Bd. 13'-5" W.Bd.
US-24	Ecorse Rd. 1.0 Mi. S. of I-94	13'-11" N.Bd. 13'-9" S.Bd.
US-24	C&O RR 0.5 Mi. N. of M-14	13'-9" S.Bd.
US-24	Wabash RR 0.1 Mi. S. of M-17	13'-8"
US-25	Penn RR in Lincoln Park	13'-10" E.Bd. 13'-10" W.Bd.
US-25 & M-17	Wabash RR in Melvindale	13'-8" E.Bd. 13'-8" W.Bd.
I-94	Schafer Hwy., in Dearborn	13'-3" E.Bd. 13'-4" W.Bd.
I-94	Rotunda Drive in Dearborn	13'-4" E.Bd. 12'-4" W.Bd.
I-94	Miller Rd. in Dearborn	13'-0" E.Bd. 13'-3" W.Bd.
I-94	Lumley Ave. in Detroit	13'-9" E.Bd. 13'-8" W.Bd.
I-94	Grand River Ave., in Detroit— Exit Ramp E.Bd. Exit Ramp W. Bd.	 11'-10" 10'-11"
I-94	Joseph Campau Ave., in Detroit— Ent. Ramp E. Bd. Ent. Ramp. W. Bd.	 13'-10" 13'-9"
I-94	Frontenac Ave., in Detroit	13'-10" W.Bd.
M-153	Miller Rd. in Dearborn	13'-9" E.Bd. 13'-8" W.Bd.
I-696 BL	Holden Ave., in Detroit	13'-10" N.Bd.
I-696 BL	Waverly Ave., in Detroit From W. Ent. Ramp S. Bd.	13'-4"

TABLE OF MAXIMUM ALLOWABLE GROSS AXLE LOADINGS

Spacing Between Axles	Normal Loadings When Restrictions Are Not In Force (speed limit 50 MPH)		Loadings When Restrictions Are in Force (speed limit 35 MPH)			
			Rigid		Flexible	
	Special Tandem Routes	Other Routes	Special Tandem Routes	Other Routes	Special Tandem Routes	Other Routes
9 feet or over	18,000 lbs.	18,000 lbs.	13,500 lbs.	13,500 lbs.	11,700 lbs.	11,700 lbs.
More than 3½ ft. but less than 9 feet	*16,000 lbs. (See Footnote)	13,000 lbs.	*12,000 lbs. (See Footnote)	9,750 lbs.	10,400 lbs.	8,450 lbs.
When less than 3½ feet the combined weight shall not exceed	18,000 lbs.	18,000 lbs.	13,500 lbs.	13,500 lbs.	11,700 lbs.	11,700 lbs.

*On any combination of vehicles only one (1) tandem assembly shall be permitted at this gross weight and no other tandem assembly shall exceed the loadings as listed.

NOTE: SPECIAL TANDEM ROUTES OR sections thereof may be revised as needed.

TABLE OF BRIDGES WITH SPECIAL LOAD LIMITS

Bridge Number On Map	Trunk Line Number	Location	Tons on Any Axle		Gross Weight (in tons)		
			9' or more Apart	Less than 9' Apart	1 *Unit	2 *Units	3 *Units
18	US-31BR	(S. Dykman) in South Haven	This bridge is limited to one lane traffic for vehicles with any axle load over 5½ tons.				
23	M-36	4.3 Mi. E. of Pinckney	5	3	—	—	—
38	M-138	1 Mi. W. of Fairgrove	—	—	13	22	31
39	M-138	2.2 Mi. W. of Fairgrove	—	—	15½	23½	31
46	M-51	S. Ruth Rd. in Ruth	8½	6	—	—	—
62	M-35	1.2 Mi. W. of Gwinn	7½	5½	22	26	31
66	US-8	2.2 Mi. of S. of Norway	7¼	5	—	—	—
73	M-26	In Eagle Harbor	This bridge is limited to one lane traffic for vehicles with any axle load over 4½ tons.				
74	M-20	In Big Rapids	—	—	16	20	24
75	M-40	In Niles	8	6	14	22	29

*One Unit—Single Truck or Bus.
Two Units—Truck and Trailer or Tractor and Semi-Trailer.
Three Units—Tractor, Semi-Trailer and Trailer.