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DEPARTMENT OF TRANSPORTATION
Bureau of Materials and Physical Research

FINAL SUMMARY REPORT

A STUDY OF THE AASHO ROAD TEST-- PHASE 2 - EVALUATION AND APPLICATION OF THE AASHO ROAD TEST RESULTS

prepared by

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A Phase of
Research Project IHR-28
AASHO Road Test

A Research Study
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16. Abstract

This report summarizes the research efforts undertaken to evaluate and apply the AASHO Road Test results to the structural design of pavements in Illinois. Presented is a brief overview of the research approach, the project accomplishments, and the implementation process utilized to put the research findings into practice. Included is a listing of all published reports, together with summaries, emanating from the project.

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TABLE OF CONTENTS

PROBLEM

The AASHO Road Test research furnished two general pavement performance equations, one applying to flexible and the other to rigid pavements. The equations express performance in terms of the number of axle-load applications required to reduce the serviceability level of the pavement to selected values, and relates this performance to the structural design of the pavement and to the magnitude and configuration of the axle load. These equations are necessarily limited in application to the specific pavements, traffic, soils, materials, and environmental conditions of the Test Road, and must be modified for application in the structural design and evaluation of highway pavements in regular service.

OBJECTIVE

The general objective of AASHO Road Test study was to develop engineering knowledge that can be used in the design of new pavements, in the evaluation and betterment of existing pavements, in the enactment of adequate and equitable taxation laws, and in the development of optimum economy between vehicle operation costs and the cost of building and maintaining highways. The specific objective of the research effort under Phase 2 of this project was to develop formulas and procedures for application of the AASHO Road Test results in structural design and evaluation of pavements in Illinois.

RESEARCH APPROACH

This research effort was undertaken in 1961 at the time of completion of the AASHO Road Test Project. At the onset of this work, two approaches were considered and weighed in relation to meeting the stated study objective. These were the construction of satellite pavements or the use of the existing highway system for the gathering of the performance data that was envisioned necessary. The latter approach was selected as the more appropriate since it would allow a more rapid collection of the performance data and would greatly facilitate development of design procedures.

The early efforts were concerned with (1) the development of a procedure for handling mixed-traffic axle loadings, and (2) ascertaining the applicability of the Road Test equations to Illinois pavements in regular service.

In developing a procedure for handling mixed-traffic axle loadings, it was necessary to consider the type of information readily available. In Illinois, this information consisted of traffic volumes, vehicle classification counts, and axle weight data. The axle weight and classification data, together with the AASHO Road Test findings, were found to provide the necessary input for the sought-after procedure. A method of traffic evaluation was developed on the basis that: (1) axle weight data obtained during any one year can be combined for all weight stations; (2) the individual weighings from Statewide weight data be placed in selected weight groupings; and (3) the data be separated for analysis according to three classifications of vehicles (passenger cars, single-unit trucks and buses, and multiple-unit vehicles).

The work on the second item was accomplished primarily by comparing the actual performance of selected Illinois highway pavements with performance predicted by the Road Test equations. Pavement sections selected were those with serviceability levels reduced to 3.0 or lower which included, insofar as possible, variations only in the particular performance variable being studied. The data analyses, indicated that the Road Test performance equations could not be applied directly, but could be suitably modified for practical application in structural design by multiplying the thickness obtained from the equations by an adjustment factor termed the Time-Traffic Exposure Factor. This factor was found to be 1.1 for flexible pavements and 1.3 for rigid pavements.

Following completion of the above, the remaining work needed to modify the performance equations to reflect conditions not included in the Road Test was initiated. These modifications included consideration of the effects of variations in the support strengths of roadbed soils and variations in the strength characteristics of the pavement structure materials. This effort was accomplished through the use of inhouse laboratory test results and guidance provided in the AASHO Interim Design Guides.

Successful completion of the above mentioned work resulted in the development of the envisioned pavement design procedures. However, the research efforts were continued with the objective of incorporating further modifications and refinements based on additional experience and research.

ACCOMPLISHMENTS

The results of the research efforts under Phase 2 of IHR-28 have provided the Department with interim procedures for the structural design of rigid and flexible pavements and the resurfacing of existing PCC pavements. These procedures permit development of the structural design for a pavement consistent with the volume and composition of traffic, the length of time the pavement is to serve the traffic, the strength characteristics of the embankment soils and pavement materials, and the minimum level of service to be provided by the pavement during its lifetime.

Through the development of the flexible pavement design procedure, the project has led to the expanded use of stabilized bases in secondary and local road construction in Illinois and, of particular significance to areas with limited sources of first quality aggregates, has aided in the development of specifications, design recommendations, and strength coefficients for use of lime stabilized soils as base and subbase.

Other project accomplishments include modifications and refinements to the design procedures reflecting the results of material studies and the updating of the traffic evaluation procedure through an analysis of recent truck weight data.

Summary of Pavement Design Process

As demonstrated by the Road Test, many factors affect the performance of highway pavements. While no design procedure has been developed which considers all of the factors, the procedures established in this study represent a major advancement in that the more significant factors are incorporated into the design process. As an example of the factors and steps involved in these procedures, the following briefly outlines the rigid pavement design process.

Step No.	Description
1	Selection of design period--The design period is the number of years in service that is desired from the pavement before it reaches a minimum serviceability level. For rigid pavement this is normally 20 years.
2	Determine structural design traffic--This is the estimated average daily traffic for the year representing one half of the design period. This ADT is subdivided into three vehicle categories--passenger cars, single-unit trucks and buses, and multiple-unit vehicles.
3	Determine the percent of structural design traffic in design lane--This is determined from either Statewide lane distribution studies or special placement studies.

Step No.	Description
4	Determine the classification of road or street-- This classification is based on the roadway's functional classification and estimated structural design traffic. Classifications range from I to IV in descending order of importance (TABLE 1).
5	Calculate the Traffic Factor (TF)--The TF is a summation of the total number of 18-kip equivalent single axle load applications, in millions, anticipated during the design period (TABLE 1).
6	Determine the soil support value of the roadway soil. Normal practice is to determine the soaked CBR of the soil to be used in the subgrade.
7	Using the TF and the CBR, find pavement type and thickness from design nomograph (Figure 1).
8	Compare the thickness and pavement type with the Department's minimum requirements (TABLE 2). Use the larger of the two values for design purposes.

The design process for both bituminous pavements and bituminous resurfacings for PCC pavements involve similar steps as outlined above, the major differences being that the use of the appropriate design nomograph (step 7) produces a pavement structural number requirement instead of a thickness. This requirement must then be satisfied by some combination of various surface, base and subbase materials (an additional step when compared with rigid design).

TABLE 1

ROAD AND STREET CLASSIFICATIONS
AND
TRAFFIC FACTOR EQUATIONS

Class I Roads and Streets (Rigid) - trunk, major, area services, and collector roads and streets designed as a four-lane or more facility, and one-way streets with a structural design traffic greater than 3,500 ADT.

$$TF = \frac{(DP)(365)(0.0004 \times U_p \times PC + 0.125 \times U_s \times SU + 1.350 \times U_m \times MU)}{1,000,000}$$

Class II Roads and Streets (Rigid) - major and area service roads and streets designed as a two-lane facility, one-way streets with a structural design traffic less than 3,500 ADT, and collector routes designed as a two-lane facility with structural design traffic greater than 2,000 ADT.

$$TF = \frac{(DP)(365)(0.0004 \times U_p \times PC + 0.116 \times U_s \times SU + 1.350 \times U_m \times MU)}{1,000,000}$$

Class III Roads and Streets (Rigid) - collector routes designed as two-lane facilities with structural design traffic between 750 and 2,000 ADT.

$$TF = \frac{(DP)(365)(0.0004 \times U_p \times PC + 0.110 \times U_s \times SU + 1.258 \times U_m \times MU)}{1,000,000}$$

Class IV Roads and Streets (Rigid) - collector and land access routes with structural design traffic less than 750 ADT.

$$TF = \frac{(DP)(365)(0.0004 \times U_p \times PC + 0.106 \times U_s \times SU + 1.216 \times U_m \times MU)}{1,000,000}$$

where: DP = design period
PC = average daily passenger-car traffic
SU = average daily single-unit traffic
MU = average daily multiple-unit traffic
U_p = percent passenger cars in design lane
U_s = percent single units in design lane
U_m = percent multiple units in design lane

TABLE 2

MINIMUM STRUCTURAL DESIGN REQUIREMENTS

ROAD AND STREET CLASSIFICATION	PORTLAND CEMENT CONCRETE PAVEMENT 1/ 2/ 3/		SUBBASE	
	TYPE	Minimum THICKNESS IN.	TYPE	Minimum THICKNESS IN.
Class I	Continuously reinforced	8	Stabilized Granular Material	4
Class II	Standard reinforced	8	Stabilized Granular Material	4
Class III	Standard reinforced	7	Granular Material 5/	4
Class IV	Standard reinforced	6	Granular Material 5/	4

1/ For municipal streets having curbs and gutters and storm sewer systems, and for which the responsibility for maintenance is to be borne entirely by the municipality, the minimum required pavement thickness shall be 6 inches. The design thickness shall in no case be less than that required by the appropriate design nomograph.

2/ Where the design thickness is 6 inches or 7 inches, standard reinforcement may be omitted at the option of the designer provided sawed transverse contraction joints are spaced no greater than 20 feet apart.

3/ A standard reinforced 10-inch pavement may be used in lieu of continuously reinforced pavement on urban sections where numerous subsurface utility adjustments are contemplated in the future for Class I roads and streets, provided prior approval is obtained from the Engineer of Design.

4/ Subbase will not be required for urban sections having curbs and gutters and storm sewer systems. However, at the designer's option, a granular subbase may be used to serve as a working platform where poor soil conditions exist. The thickness of the subbase shall be determined by the designer.

5/ Pavement for Class III and Class IV roads and streets may be designed with or without a subbase, at the designer's option, providing the traffic factor does not exceed 0.7.

PORTLAND CEMENT CONCRETE PAVEMENTS

CLASS I ROADS AND STREETS

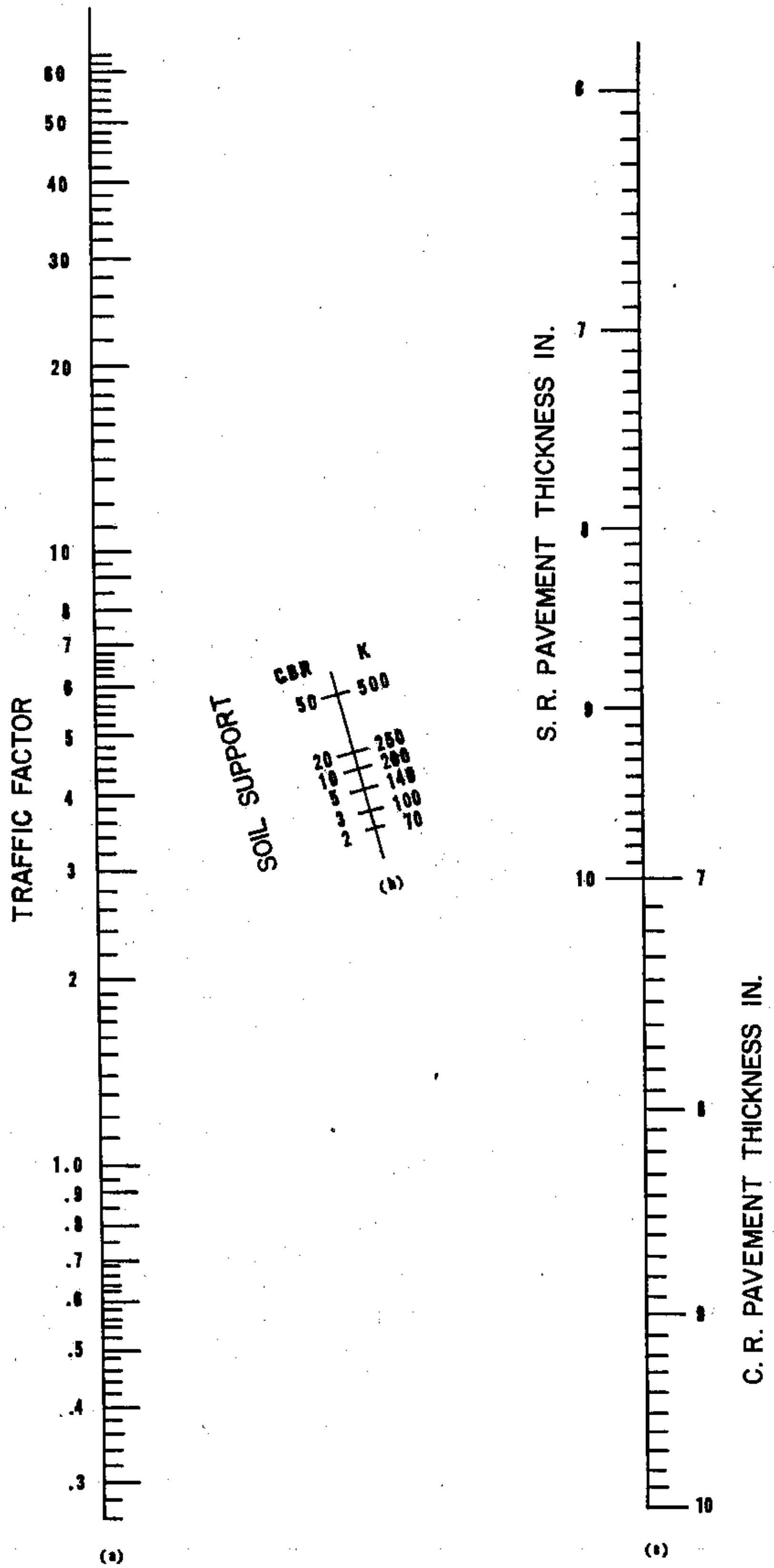

Figure 1

IMPLEMENTATION

The results of this project have been implemented into practice. The more formal research type reports resulting from the project have been transformed into a format satisfactory for use in design, and incorporated into Section 7 of the Department's Design Manual. This effort involved a coordinated effort between the research staff and Department personnel directly concerned with pavement design.

In order to aid in the implementation process, seminars were presented throughout the State. These seminars concerned not only the presentation of the developed design procedures, but were used to acquaint the attendees with their background. This included a review of the AASHO Road Test results, and the research involved in translating the Road Test results into pavement design procedures.

Implementation of the project results has allowed the designer for the first time to determine a pavement design on the basis of the volume and composition of mixed truck and passenger car traffic to be served, the length of time the pavement is to serve this traffic, the materials to be used, the soils that will be encountered, and the minimum level of service to be provided by the pavement during its lifetime. This has to be considered a significant achievement when previous pavement designs were selected through the use of design standards that had been developed through an evolutionary process.

Quantification of the economic benefits derived from implementation of research findings is difficult to assess. In order to arrive at a realistic answer, it is necessary to make a simplifying assumption that all pavements built since the adoption of the present design policies would have been built in accordance with the previous typical design standards. With this assumption, it is possible to derive total pavement costs over a 20-year design life for each of the two conditions. The results of this analysis indicate an estimated annual cost saving of $2,565,000 per year. Assuming a 15-year period as the useful life for the present design procedures, and uniformly spreading the project costs over this period, indicate a benefit/cost ratio of 25.

PUBLISHED REPORTS WITH SUMMARIES

1. "Application of Road Test Formulas in Structural Design of Pavement," by W. E. Chastain, Sr., Highway Research Board - Special Report No. 73, The AASHO Road Test: St. Louis Conference Proceedings, May 1962.

This paper discusses the work being done in examining the Road Test performance equations by comparing the performance of Illinois pavements of various designs serving under varying traffic conditions for variable periods of time, with the performance predicted by the equations.

The study results encourage the belief that the Road Test performance equations can be modified suitably for practical application to rural highway pavements serving under normal environmental conditions by applying data from existing pavements. It also appears that the equations cannot be applied to regular rural highway pavements without modifications, at least under conditions typical of much of the Midwest. Definite trends were established between actual performance of Illinois pavements and the performance as predicted by the Road Test equations when suitably modified. The study suggests relatively simple procedures for developing factors to modify the equations so that they can be applied directly to the design and evaluation of highway pavements.

2. "AASHO Road Test Equations Appllied to the Design of Bituminous Pavements in Illinois," W. E. Chastain, Sr., and D. R. Schwartz, Illinois Division of Highways, Research and Development Report No. 1, October 1964 (Highway Research Board Record No. 90, 1965).

This report is considered with the work done in applying the findings of the Toad Test flexible pavement research to the structural design of bituminous pavements in Illinois. It presents background information and concepts used in developing the design procedure, describes the development of the procedure, and demonstrates its application.

The procedure provides for establishing the types and thicknesses of materials to be used in the various layers of the pavement structure consistent with the volume and composition of traffic, the length of time the pavement is to serve this traffic, the strength characteristics of the subgrade soils and pavement materials, and the minimum level of service to be provided by the pavement during its lifetime.

The AASHO Road Test flexible pavement performance equation serves as the basis of this design procedure. The equation explains performance of the test sections as related to pavement design, the magnitude and configuration of the axle load, and the number of axle-load applications. This equation necessarily is limited to the physical environment of the project; to the materials used in the test pavements; to the range in pavement thicknesses included in the experiment; to the axle loads, number of axle-load applications, and the specific times and rates of application of the test traffic; to the construction techniques employed; and to the climatic cycles experienced during construction and testing of the experimental facility. To apply the equation in the design of regular highway pavements, it was necessary to make certain assumptions and extrapolations based on experience and engineering judgment. As additional knowledge is gained through further research and experience, the precision of these assumptions and extrapolations should become sharpened. Therefore, the design procedure presented is provisional in nature and is subject to modification based on addition experience and research.

3. "AASHO Road Test Equations Applied to the Design of Portland Cement Concrete Pavements," W. E. Chastain, Sr., J. A. Beanblossom, and W. E. Chastain, Jr., Illinois Division of Highways, Research and Development Report No. 2, October 1964 (Highway Research Board Record No. 90, 1965).

This report presents and describes the development of a procedure for applying the results of the Road Test rigid pavement research to the structural design of portland cement concrete pavements in Illinois.

The developed procedure provides a means for determining the types and thicknesses of concrete slab so that, on the average, the pavement will be capable of carrying a specific volume and composition of mixed traffic and passenger car traffic for a designated period of time and, at the same time, retain a level of serviceability at or above a designated minimum.

The AASHO Road Test rigid pavement performance equation serves as the basis of this design procedure. The equation explains performance of the test sections as related to pavement design, the magnitude and configuration of the axle load, and the number of axle-load applications. This equation necessarily is limited to the physical environment of the Project; to the materials used in the test pavements; to the range in pavement thicknesses included in the experiment; to the axle loads, number of axle-load applications, and the specific times and rates of application of the test traffic; to the construction techniques employed; and to the climatic cycles experienced during construction and testing of the experimental facility. To apply the equation in the design of regular highway pavements, it was necessary to make certain assumptions and extrapolations based on experience and engineering judgment. As additional knowledge is gained through further research and experience, the precision of these assumptions and extrapolations should become sharpened. Therefore, the design procedure presented is provisional in nature and subject to modification based on additional experience and research.

4. "Procedure for the Selection of Asphalt Concrete Resurfacing Thickness," D. R. Schwartz and C. R. Warning, Highway Research Board Record No. 300, 1969.

This paper discusses the work undertaken to develop an empirical design procedure for composite pavement. This effort is a continuation of the work to evaluate the findings of the AASHO Road Test so that they can be applied to the structural design of regular highway pavements in Illinois.

The work on an interim procedure for determining the thickness of resurfacing needed in rehabilitating existing PCC pavements had not been completed but had progressed to a point where it appeared that the study would be successful. Presented in detail are the basic assumptions, the preliminary data analyses, and a brief overview of the remaing work to be accomplished.

5. "Design Coefficients for Lime-Soil Mixtures," Illinois Division of Highways, Research and Development Report No. 22, January 1970.

The findings of research project IHR-76, "Lime Stabilization of Soils for Highway Purposes," have indicated that lime-soil mixtures can be used effectively and economically as quality highway construction materials. The work described in this report was undertaken to permit application of the findings of IHR-76 in pavement design by developing tentative strength coefficients and materials requirements and limitations for inclusion of the use of lime-stabilized-soil mixtures as base and subbase in the Illinois Flexible Pavement Structural Design Procedure.

The report presents a brief summary of the IHR-76 findings germane to the reported effort, summarizations of available information on pavements actually constructed with a lime-stabilized soil as an integral part of the pavement structure, and a detailed discussion of the procedure utilized in developing strength coefficients for lime-stabilized soils. Also presented are design limitations which are to be followed when utilizing this material in the pavement structure.

6. "Thickness Design Procedure for Bituminous Resurfacing of Portland Cement Concrete Pavements," R. P. Elliott, Illinois Division of Highways, Research and Development Report No. 30, November 1971.

Performance data were collected from 89 resurfaced PCC pavements and were studied relative to the performance predicted for new pavements by the Illinois rigid and flexible design procedures. This analysis revealed that the performance of a resurfaced pavement resembles the performance of a rigid pavement more closely than it does the performance of a flexible pavement. Based on this finding a resurfacing design procedure for both first and second resurfacings was developed by modifying the currently used rigid pavement procedure. It was subsequently demonstrated that adoption of this procedure would result in a significant improvement in the Division's resurfacing design capability.

Being developed by modifying the existing procedure, the resurfacing procedure utilizes the same format as the existing procedures and considers the same design parameters -- traffic, soil support, and material thicknesses. Traffic is evaluated in terms of equivalent 18-kip single-axle load applications based on the AASHO Road Test performance equation for rigid pavements. Material thicknesses are included in a linear, structural number relationship similar to that employed in the Illinois and AASHO Interim Guide procedures for flexible pavements. The design analysis is presented in the form of nomographs which include the three design paramters.

7. "Traffic Evaluation for Illinois Pavement Design," W. E. Chastain, Jr, and R. P. Elliott, Illinois Department of Transportation, Research and Development Report No. 36, April 1972.

In 1964, the Illinois Division of Highways adopted interim design procedures for flexible and rigid pavements. These procedures were based on modifications of the performance equations developed from the AASHO Road Test data. A principal parameter included in the procedures is the type and amount of traffic anticipated for the facilities. Through a numerical relationship, called the Traffic Factor, the anticipated traffic is evaluated and reduced to a single expression. The vehicle equivalency factors used in this relationship were established from an analysis of loadometer and classification count data available at the time the procedures were developed. An analysis of additional data gathered in subsequent years indicates a need for revising and updating these equivalency factors. This paper describes the original development of the traffic evaluation method and presents an analysis of the more recent loadometer and classification count data. Based on this analysis, updated vehicle equivalency factors are recommended.

8. "Traffic Evaluation for Secondary and Local Pavement Design," R. P. Elliott, Illinois Department of Transportation, Physical Research Report No. 49, June 1973.

When the Illinois pavement design procedures were developed, no truck weight data and only a limited amount of vehicle classification data were available from secondary and local roads. As a result, the vehicle equivalency factors used in traffic analyses for the design of these roads were based on extrapolations of data from primary highways and assumptions that produced pavement design requirements consistent with past experience. The current study was conducted to determine the relative reliability of these factors and, if possible, to establish more realistic values.

Truck weight data from local and secondary roads were still unavailable. However, sufficient classification data were available to compute VEFs for both Class III ($400 < \text{ADT} < 1,000$) and Class IV ($\text{ADT} < 400$) roads while using the truck weight data from primary highways. This produced the VEFs that were previously recommended for use in the design of flexible and rigid pavements on Class III roads and rigid pavements on Class IV roads. However, the flexible pavement VEFs for Class IV roads from this analysis were considered unrealistic since their use would require heavier pavement designs than are deemed necessary.

To determine other elements that influence the value of the vehicle equivalency factors, the effect of seasonal traffic fluctuations was evaluated at the AASHO Road Test performance equation and the method of converting mixed traffic to an equivalent single loading were studied. Seasonal traffic fluctuations were found to have a potentially significant effect on the average value of the vehicle equivalency factors. However, the effect is not sufficient to explain the difference between the currently used Class IV road VEFs and the ones determined from classification data. The study of the performance equation and method of traffic conversion, while not producing evidence that could be used to verify or adjust the VEFs, provided considerable insight into the nature of the performance equation and demonstrated that for typical Class IV pavement designs the conversion of mixed traffic can produce questionable results.

Finally, performance data from various county highways were analyzed. This showed that the Class III road VEFs provided a reasonable estimate of the effect of mixed traffic on both Class III and Class IV roads. Nevertheless, for Class IV flexible pavement design, retention of the original VEFs has been recommended on the basis of past experience, possible differences in design philosophy between primary and secondary pavement designers and the questionable applicability of the Present Serviceability Index and the performance equation as extended in the Illinois design procedure to the design of Class IV roads.