Use of AASHO Road Test Findings by the AASHO Committee on Highway Transport

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This paper, prepared as part of an over-all symposium on the results of the AASHO Road Test sponsored by the Highway Research Board, deals with the subject of how the AASHO Committee on Highway Transport proposes to use the findings of the AASHO Road Test in developing the new AASHO "Recommended Policy on Maximum Dimensions and Weights of Motor Vehicles."

The subject is treated in three parts: (1) a brief review of background material; (2) major findings applicable to the committee's assignment; and (3) considered use of the findings. Furthermore, the paper has been prepared to serve as a technical guide to members of the Committee on Highway Transport.

With this objective in mind, the paper is documented with graphs, tables, and simplified equations suitable for use by those interested in any particular phase of the subject.

• The purpose of this report is to explain how the findings of the AASHO Road Test may be used by the AASHO Committee on Highway Transport to develop a new "Recommended Policy on Maximum Dimensions and Weights of Motor Vehicles Operated on the Nation's Highway Systems."

In November 1932, the Association adopted its first policy concerning maximum sizes, weights, and speeds of motor vehicles to be operated over the highways of the United States.

In 1944, the Highway Transport Committee gave initial consideration to a revision of the 1932 Policy and of the substitute recommendations adopted in May 1942 for the duration of the war emergency.

In January 1946, the Highway Transport Committee transmitted to the AASHO Executive Committee a recommended policy concerning maximum dimensions, weights, and speeds of motor vehicles. This document, known as the 1946 Policy on Dimensions, Weights, and Speeds of Vehicles, was adopted by the Association on April 1, 1946, and is now in force.

In 1950, the AASHO completed plans for a series of regional accelerated controlled-traffic road tests. The purpose was to determine the effect of specific axle loads frequently applied at known speeds on existing representative pavements. The data from these tests would be used for policy determination of legal limits of loads. The responsibility for establishment of the regional road test program was assigned to the AASHO Committee on Highway Transport.

Between 1951 and 1955, the Highway Transport Committee gave serious consideration to a revision of the 1946 Policy. It was also decided to continue study but delay final action on revising the 1946 Policy until results of the AASHO Road Test were available.

In 1956 the Association assigned the following responsibilities to the Highway Transport Committee:

1. At the conclusion of the AASHO Road Test to be ready to present a Recommended Policy on Vehicle Sizes and Weights to the Association, and
2. To recommend to the Association any economic studies regarding the equitable financing of highways by the various classes of highway users.

The new policy is being prepared with the assistance of the AASHO Committee on Design, the AASHO Committee on Bridges and Structures, the Bureau of Public Roads, the Highway Research Board, and in cooperation with the Transport Industry groups and the States. These various agencies are directing their respective efforts to the common objective.

AASHO Committee on Design

The AASHO Committee on Design was assigned the responsibility of reviewing the engi-

neering findings resulting from the AASHO Road Test and furnishing the Highway Transport Committee with such approved data as would be useful in developing the proposed Policy. With respect to this assignment, the Design Committee completed separate AASHO Interim Guide Manuals (*1*), for the design of rigid and flexible pavements. This work was completed in February 1962. The contents of these Design Manuals will be used as a guide by the Highway Transport Committee in completing its assignment.

AASHO Committee on Bridges and Structures

The AASHO Committee on Bridges and Structures is advising the Highway Transport Committee on matters pertaining to any proposed changes of load requirements in relation to the existing bridge structures on the various highway systems. Furthermore, they are assisting in determining the load carrying capacity of existing bridges in relation to the over-all evaluation of the load carrying capacity of the nation's highway plant.

Bureau of Public Roads

Under the provisions of the Federal Highway Act of 1956 (*2*), the Bureau of Public Roads with help of the States and other agencies was called upon to carry out five major studies. One of the studies, described in Section 108 (k) of the Act, pertains to determining maximum desirable sizes and weights for vehicles operated on the Federal-aid highway systems, by using the results of the AASHO Road Test. With the Road Test now concluded, the Bureau of Public Roads is expected to make recommendations to the Congress with respect to such maximum desirable dimensions and weights.

Further, the fifth and final study, outlined in Section 210, calls for an analysis of the cost of providing highway facilities for different classes of vehicles, and of the benefits derived from highway use by all classes of users. These figures must be determined for all Federal-aid highway systems, the purpose being to provide Congress with a basis for determining "equitable" rates of taxation on highway users and other beneficiaries. The Bureau of Public Roads is also expected to report to the Congress the results of their study on this section.

Since the two Bureau of Public Roads' assignments are also closely related to the current assignments of the AASHO Transport Committee, the two agencies are cooperating actively to the end that their final results will be consistent and thus be acceptable to all parties concerned.

Highway Research Board

The Highway Research Board Committee on Economics of Motor Vehicle Size and Weight, well staffed by the Bureau of Public Roads, has made considerable progress toward completion of the Bureau's assignment, also described in Section 210 of the 1956 Federal Highway Act.

The purpose of this committee is to guide and assist in the collection of economic data pertinent to the solutions of the problems of truck size and weight related to highway design. The job is a cooperative one, with different agencies and organizations collecting field data and then acting together under regular procedures of the Highway Research Board. The raw data will be processed by the Highway Transport Research Branch, Division of Research, Bureau of Public Roads. The processed data will be used by AASHO and the Bureau of Public Roads to determine what maximum size and weight specifications for freight vehicles, with corresponding maximum weight specifications for pavement and bridge construction, will result in the most economical over-all highway transportation costs for commodities and freight in the United States.

The AASHO Road Test staff, under the direction of the Highway Research Board, has also been very cooperative in furnishing the AASHO Highway Transport Committee with advanced engineering data and, when requested, technical assistance, as well as advice on Road Test matters having relation to supporting information for the proposed AASHO Policy on Maximum Dimensions and Weights.

Transport Industry Groups

On two occasions joint meetings have been held with the Transport Industry groups to discuss matters of mutual interest pertaining to vehicle sizes and weights. These meetings served to point out the particular areas of concern to the different industry groups and to guide the Transport Committee in its future deliberations. Subsequently, the Transport Industry groups received approval to appoint a small technical advisory committee to work with the Highway Transport Committee on special assignments of a technical nature concerning the design and operating characteristics of commercial vehicles.

The Highway Economic and Engineering Problem

In developing the AASHO Road Test project, the sponsors recognized the existence of an over-all highway economic and engineering problem consisting of four basic parts based on the following assumptions:

Part 1—Unit Cost of Carried Loads.—This is based on evidence that economies in commercial motor vehicle operation can be obtained by the use of vehicles with greater axle loads and gross weights than are now allowed. The

law of diminishing returns will apply at some maximum limit, the magnitude of which has not yet been fully determined.

Part 2—Unit Cost of Extra Highway Provision.—This is also based on evidence that pavement construction costs increase with provision for increased load-supporting capacity in some relation not fully established.

Part 3—Basic Unit Highway Cost for Passenger Cars.—There exists a basic cost necessary to provide highways for passenger cars with cognizance of the destructive effects of climatic conditions, a value which has not been firmly established for different types of highways.

Part 4—Taxation.—It is possible to determine the highway cost responsibility of various classes of highway users as a basis for more equitable taxation.

The inter-relationship of these four parts has been interpreted graphically in Figure 1, from which it follows that at a certain point the combined costs of vehicle operation and highway provision will be a minimum. The problem is to determine this optimum balance point, by a combination of engineering and economic studies.

The engineering aspect of the over-all highway transportation problem involves two considerations, the vehicle and the highway, both of which include certain economic elements. The findings of the AASHO Road Test will be applied by the AASHO Committee on Highway Transport to the considerations suggested by Parts 2 and 3. In this work, special consideration will be given to the following objectives:

1. The design of pavements adequate to carry present and future axle loads and gross vehicle weights.
2. The determination of the extra cost of highway provision for future axle loads and gross vehicle weights which may be justified by the over-all highway transport economy.

The New Policy

In preparing the new AASHO Policy on Maximum Dimensions and Weights of Vehicles, it is fully recognized that (a) the 1946 AASHO Policy on Maximum Dimensions and Weights of Vehicles has not been uniformly adopted into the laws of the States, and (b) that this is a project of national significance. Therefore, any decisions affecting the Highway Transport Industry will be made by joint effort. Further, it is understood that any policy concerning vehicle sizes and weights should meet the following criteria:

1. It must be based on economic considerations as well as physical relationships between the vehicle and the roadway.
2. It should promote uniform regulations among the States and on the Interstate System as well as State primary highways.
3. It should, if possible, simplify the Bridge Formula Rule.
4. The Policy must appeal to vehicle operators and must be simple to enforce.
5. The National and Regional aspects of the over-all problem must be recognized.
6. The Policy should foster better load distribution and give appropriate consideration to all types of vehicles using the highways.
7. Insofar as practicable, the Policy should

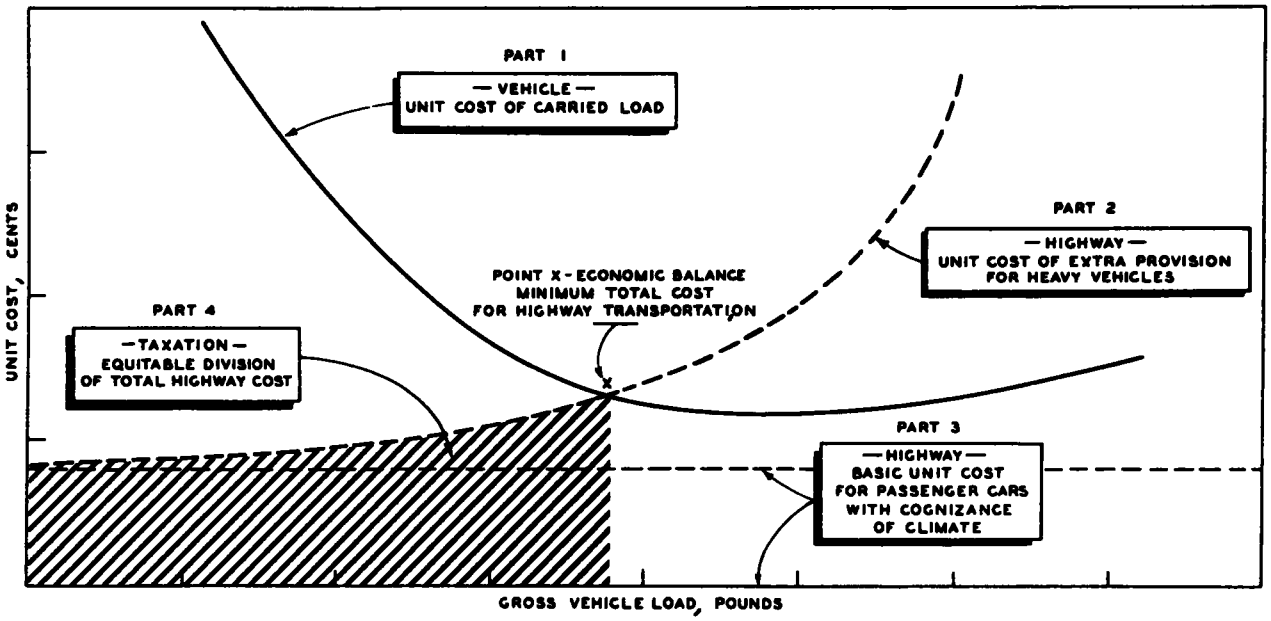

Figure 1. The highway transport economic and engineering problem.

improve transport conditions within reasonable axle-load limits of vehicles.

8. The Policy should be realistic concerning conditions not only in the immediate future but for those anticipated as far ahead as 1975.

The Highway Transport Committee proposes to prepare a new AASHO Policy on Maximum Dimensions and Weights of Vehicles through modification or revision of the existing 1946 Policy, supported by data from the AASHO Road Test; from studies by the Bureau of Public Roads to fulfill the requirements of the 1956 Federal Highway Act; from studies by the Highway Research Board Project Committees; from the Operating Committees of AASHO; and from other reliable sources acceptable to the Highway Transport Committee. Further, it is assumed that the Policy being developed will be properly recognized and acceptable of all of the States and, in turn, will be incorporated into their respective State codes of motor vehicle laws, thereby eventually effecting uniform transport conditions throughout the nation.

The authors have elected to discuss their subject by first presenting a brief summary of the findings from the Road Test considered to be most applicable to the Committee's problems, and, second, by discussing how these selected findings may be used to support the Committee's mission.

SIGNIFICANT FINDINGS FROM THE ROAD TEST

This section describes briefly the significant findings from the Road Test which will be considered for use by the Committee on Highway Transport. They include:

1. The Pavement Serviceability-Performance Concept (*3*).
2. The AASHO Road Test equations for rigid and flexible pavements.
3. Axle-load equivalence factors derived from Road Test equations.
4. Single- and tandem-axle equivalences.

Serviceability-Performance Concept

By definition Present Serviceability is the ability of a specific section of pavement to serve high-speed, high-volume, mixed (truck and automobile) traffic in its existing condition. Performance of a pavement then can be described by its serviceability history from the time it was built to the time its performance evaluation is obtained.

The present serviceability rating (PSR) of a section of pavement can be obtained in two ways:

1. By indicating on an appropriate adjective scale the present physical quality of the pavement as determined from visual and other sensory observations (Figure 2a).

   a. The serviceability rating may be based on the judgments of one or more persons riding a pavement and rating the pavement on basis of experience, or

   b. The serviceability rating may be based on descriptive data available in State Highway Sufficiency Rating Summaries.

2. By obtaining certain physical measurements which can be substituted into a mathematical expression from which a value called the Present Serviceability Index (PSI) can be obtained.

   a. Physical measurements on rigid pavement would include average slope variance in both wheelpaths as measured by the AASHO profilometer or roughness as measured by the Bureau of Public Roads type of roughometer. Roughness data from the roughometer must be correlated with that from the AASHO profilometer. In addition, major cracking in linear feet per 1,000 sq ft of pavement area, and bituminous patching in square feet per 1,000 sq ft of pavement area are required.

   b. Physical measurements on flexible pavement would include, in addition to slope variance or roughness as described above, the determination of area cracking in square feet per 1,000 sq ft of surface area, skin or deep patching in square feet per 1,000 sq ft of surface area, and rut depth in inches measured at the center of a 4-ft span in the deepest part of the rut.

PSI equations for rigid and flexible pavements are follows:

Rigid Pavement:

$$\text{PSI} = 5.41 - 1.80 \log(1 + \overline{SV}) - 0.09\sqrt{\overline{C + P}} \quad (1)$$

Flexible Pavement:

$$\text{PSI} = 5.03 - 1.91 \log (1 + \overline{SV}) - 0.01 \sqrt{\overline{C + P}} - 1.38 (\overline{RD})^2 \quad (2)$$

Terms of Eqs. 1 and 2 are defined in Appendix A, which also demonstrates use of the equations.

Pavement performance may be determined by measuring its serviceability index immediately after construction and at intervals until it is resurfaced or retired. If such information is plotted as in Figure 2b, a serviceability-performance history graph would result. Obviously, such a graph may find many uses.

The AASHO Road Test Equations

The specific objectives of the AASHO Road Test stated by the National Advisory Committee in April 1957 will be found in Highway Re-

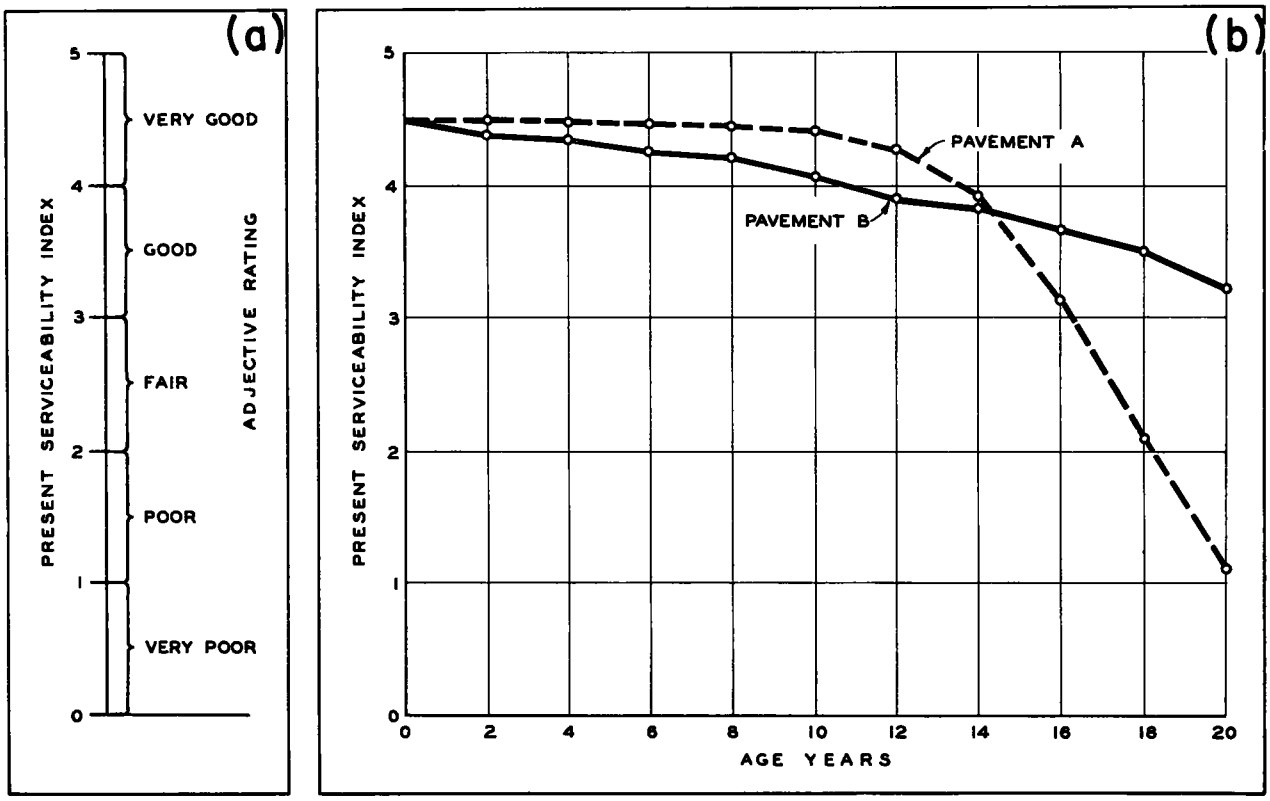

Figure 2. Serviceability-performance concept: (a) rating form; (b) serviceability-performance history.

search Board Special Report 61A. The first and most important of these objectives was as follows:

> To determine the significant relationships between the number of repetitions of specified axle loads of different magnitude and arrangement and the performance of different thicknesses of uniformly designed and constructed asphaltic concrete, plain portland cement concrete and reinforced portland cement concrete surfaces on different thicknesses of bases and subbases when on a basement soil of known characteristics.

By extrapolating from the Road Test data, it is possible to express these relationships for rigid and flexible pavements both mathematically as in Eq. 3 and graphically (Fig. 3). The terms used in Eq. 3 are defined in Appendices B and C, in which this equation is also developed further.

$$G_t = \beta \ (\log W_t - \log \rho) \qquad (3)$$

The AASHO Road Test equations also provide means for determining the relationships between the weight and frequency of axle loadings and pavement performance. The equations permit the determination of pavement thickness for any given loading condition, and the effect on pavement life of any change in axle load or frequency from that condition.

Structural Relationship Between Rigid and Flexible Pavement

It is possible by means of the fundamental AASHO Road Test equations to develop certain basic engineering data necessary for the completion of the AASHO Policy and for other related purposes which will be discussed later. As an example, Figure 4 has been prepared from the basic Road Test equations to indicate the relation between rigid pavement thickness and corresponding required strength of flexible pavement represented by the structural number $\overline{SN}$. Such information is needed for effective evaluation of the load-carrying capacity of the national highway plant.

Equivalence Factors

A significant development from the AASHO Road Test equations is a series of axle-load equivalence factors from which it is possible to determine the effects on the pavement structure of one axle load as compared to another. This is done by writing the AASHO Road Test equation in the following form:

$$\log W_t = \log \rho + \frac{G_t}{\beta} \qquad (4)$$

The ratio of W_{t_x} to W_{t_y} expresses the relationship of an axle load, x, to any other axle load, y, single or tandem. This development permits

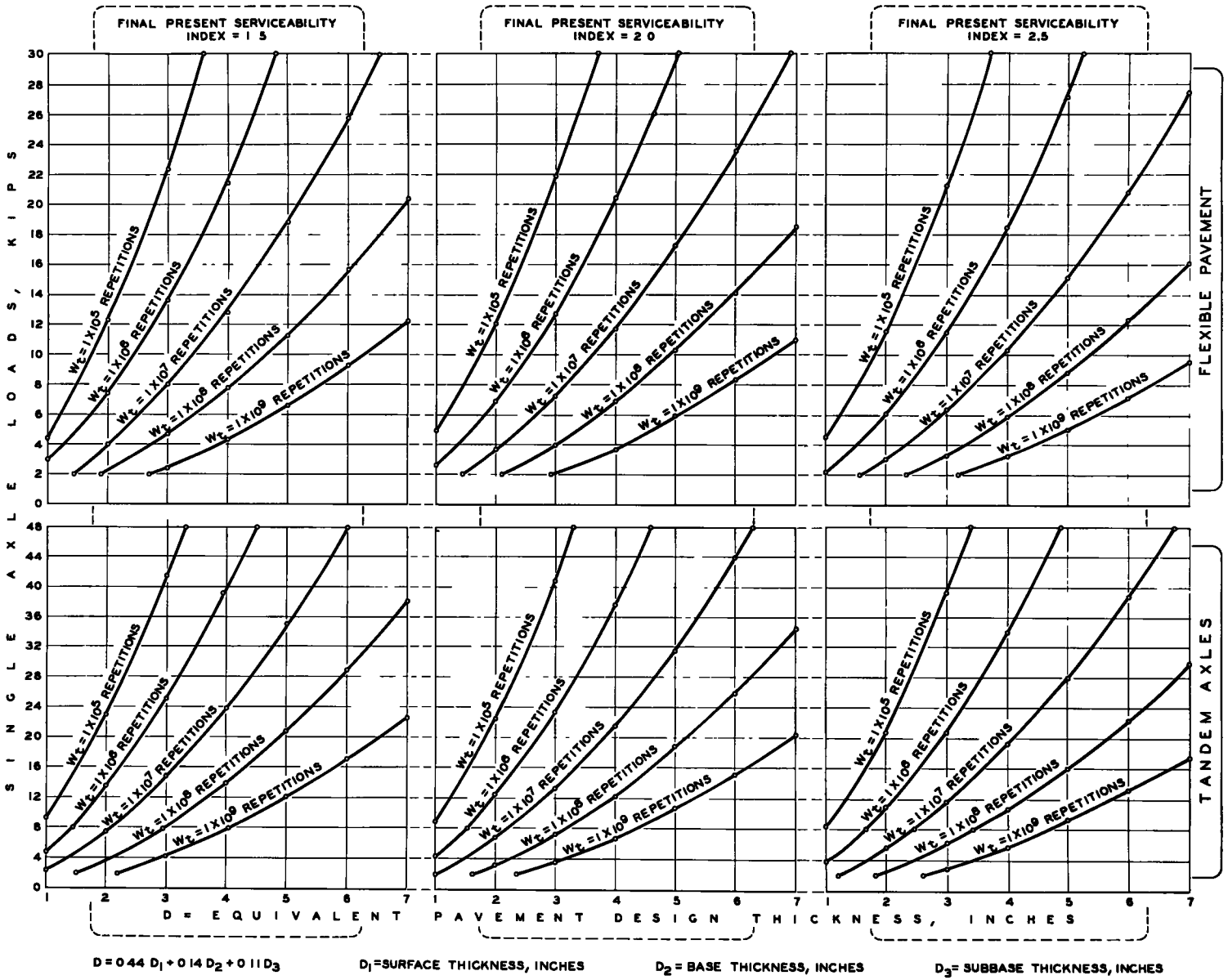

Figure 3. Relationships among axle loads, axle frequency, pavement type and thickness, and terminal serviceability index.

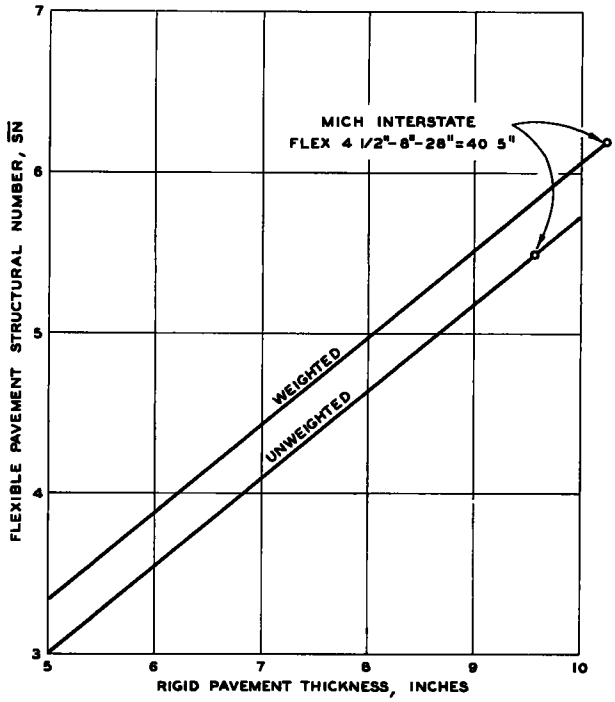

Figure 4. Relation between rigid pavement thickness and flexible pavement structural number with terminal serviceability index of 2.0.

the conversion of all axle load applications encountered in mixed traffic to an equivalent selected load category (for example, 18,000-lb) in which case, W_{t_x} becomes $W_{t_{18}}$. These ratios, known as equivalence factors, when multiplied by the number of axle loads within a given weight category would indicate the number of 18,000-lb single-axle load applications that will have an equivalent effect on the performance of the pavement structure.

Average values for the equivalence factors for both rigid and flexible pavements, where W_{t_x} equals an 18-kip single-axle load, are given in Tables 1 and 2. The method used by the AASHO Committee on Design to compute equivalence factors from the Road Test equation will be found in Appendices D and E.

Figure 5 has been prepared from the Road Test equations, as shown in Appendices F and G, to show the relationship between pavement thickness, 18-kip single-axle load frequency, certain serviceability indices, and the two types of pavement. The values were extrapolated from the actual Road Test findings. From the relationships shown, several determinations are readily obtainable, for example:

1. By converting present mixed ADT to equivalent 18-kip single-axle loads and knowing their frequency, pavement thickness can be determined for any selected period of service.
2. Also, the additional pavement thickness needed to meet any increase in 18-kip single-axle loads or frequencies can be determined.

Single-Axle and Tandem-Axle Equivalences

The single-axle and tandem-axle load equivalences can be determined from the AASHO Road Test equations contained in Appendices D and E, or directly from the equivalence factors in Tables 1 and 2. This information is important and is needed as a basis for establishing axle load limits.

Figure 6 shows the equivalence relationship for a range of single and tandem axles on rigid and flexible pavements, based on Road Test data. The approximate results from averaging the two curves in Figure 6 are given in Table 3.

USE OF FINDINGS

This section is devoted to a brief discussion of possible uses of the Road Test findings in partial solution of the transport economic and engineering problem, and in development of the new AASHO Policy on Maximum Dimensions and Weights of Motor Vehicles. It is important to note that the Road Test information cannot always be applied directly to each problem confronting highway engineers. In most instances, the Road Test data can be used only as an aid in applying individual engineering judgment. Many applications suggested in the following discussion are based directly on engineering judgment tempered with AASHO Road Test information.

One of the first important uses of the Road Test findings will be in connection with a nationwide pavement evaluation survey to be made by the States in cooperation with the Bureau of Public Roads and the Association, with two immediate objectives:

1. To evaluate the status of the load-carrying capacity of the existing national highway plant as of January 1, 1962; and
2. With the first objective achieved, then to appraise the effect of changes in axle loads on the rate at which pavements must be resurfaced or replaced and the cost involved, and to determine the axle-load limits that will allow a pavement life expectancy compatible with the State's financial ability to resurface or replace the pavement.

From this survey, engineering data will be acquired for use by the Bureau and the Association in recommending future axle-load limits to Congress and the States, respectively.

The Road Test equations will be used to estimate the remaining life expectancy of existing pavements under (a) present axle-load limits, and (b) higher axle-load limits. This will permit the different axle-load limits to be appraised in terms of their effects on acceleration of the normal program of pavement resurfacing and reconstruction.

The inventory will include all State highways (both rural and urban) with certain excep-

TABLE 1

RIGID PAVEMENT EQUIVALENCE FACTORS*
(W_{t_a} = 18-Kip Single-Axle Load)

	SINGLE AXLE						TANDEM AXLE					
	Gross Axle Load, kips	D - Slab Thickness, inches						Gross Axle Load, kips	D - Slab Thickness, inches				
		6	7	8	9	10	11		6	7	8	9	10	11
P = 20	2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	10	0.01	0.01	0.01	0.01	0.01	0.01
	4	0.002	0.002	0.002	0.002	0.002	0.002	12	0.03	0.03	0.03	0.03	0.03	0.03
	6	0.01	0.01	0.01	0.01	0.01	0.01	14	0.05	0.05	0.05	0.05	0.05	0.05
	8	0.03	0.03	0.03	0.03	0.03	0.03	16	0.09	0.08	0.08	0.08	0.08	0.08
	10	0.09	0.08	0.08	0.08	0.08	0.08	18	0.14	0.14	0.13	0.13	0.13	0.13
	12	0.19	0.18	0.18	0.18	0.17	0.17	20	0.22	0.21	0.21	0.20	0.20	0.20
	14	0.35	0.35	0.34	0.34	0.34	0.34	22	0.32	0.31	0.31	0.30	0.30	0.30
	16	0.61	0.61	0.60	0.60	0.60	0.60	24	0.45	0.45	0.44	0.44	0.44	0.44
	18	1.00	1.00	1.00	1.00	1.00	1.00	26	0.63	0.64	0.62	0.62	0.62	0.62
	20	1.55	1.56	1.57	1.58	1.58	1.59	28	0.85	0.85	0.85	0.85	0.85	0.85
	22	2.32	2.32	2.35	2.38	2.40	2.41	30	1.13	1.13	1.14	1.14	1.14	1.14
	24	3.37	3.34	3.40	3.47	3.51	3.53	32	1.48	1.45	1.49	1.50	1.51	1.51
	26	4.76	4.69	4.77	4.88	4.97	5.02	34	1.91	1.90	1.93	1.95	1.96	1.97
	28	6.59	6.44	6.52	6.70	6.85	6.94	36	2.42	2.41	2.45	2.49	2.51	2.52
	30	8.92	8.68	8.74	8.98	9.23	9.39	38	3.04	3.02	3.07	3.13	3.17	3.19
	32	11.87	11.49	11.51	11.82	12.17	12.44	40	3.79	3.74	3.80	3.89	3.95	3.98
	34	15.55	15.00	14.95	15.30	15.78	16.18	42	4.67	4.59	4.66	4.78	4.87	4.93
	36	20.07	19.30	19.16	19.53	20.14	20.71	44	5.72	5.59	5.67	5.82	5.95	6.03
	38	25.56	34.54	24.26	24.63	25.36	26.14	46	6.94	6.76	6.83	7.02	7.20	7.31
	40	32.18	30.85	30.41	30.75	31.58	32.57	48	8.36	8.12	8.17	8.40	8.63	8.79
P = 25	Gross Axle Load, kips	D - Slab Thickness, inches						Gross Axle Load, kips	D - Slab Thickness, inches					
		6	7	8	9	10	11		6	7	8	9	10	11
	2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	10	0.01	0.01	0.01	0.01	0.01	0.01
	4	0.003	0.002	0.002	0.002	0.002	0.002	12	0.03	0.03	0.03	0.03	0.03	0.03
	6	0.01	0.01	0.01	0.01	0.01	0.01	14	0.06	0.05	0.05	0.05	0.05	0.05
	8	0.04	0.04	0.03	0.03	0.03	0.03	16	0.10	0.09	0.08	0.08	0.08	0.08
	10	0.10	0.09	0.08	0.08	0.08	0.08	18	0.16	0.14	0.14	0.13	0.13	0.13
	12	0.20	0.19	0.18	0.18	0.18	0.17	20	0.23	0.22	0.21	0.21	0.20	0.20
	14	0.38	0.36	0.35	0.34	0.34	0.34	22	0.34	0.32	0.31	0.31	0.30	0.30
	16	0.63	0.62	0.61	0.60	0.60	0.60	24	0.48	0.46	0.45	0.44	0.44	0.44
	18	1.00	1.00	1.00	1.00	1.00	1.00	26	0.64	0.64	0.63	0.62	0.62	0.62
	20	1.51	1.52	1.55	1.57	1.58	1.58	28	0.85	0.85	0.85	0.85	0.85	0.85
	22	2.21	2.20	2.28	2.34	2.38	2.40	30	1.11	1.12	1.13	1.14	1.14	1.14
	24	3.16	3.10	3.23	3.36	3.45	3.50	32	1.43	1.44	1.47	1.49	1.50	1.51
	26	4.41	4.26	4.42	4.67	4.85	4.95	34	1.82	1.82	1.87	1.92	1.95	1.96
	28	6.05	5.76	5.92	6.29	6.61	6.81	36	2.29	2.27	2.35	2.43	2.48	2.51
	30	8.16	7.67	7.79	8.28	8.79	9.14	38	2.85	2.80	2.91	3.04	3.12	3.16
	32	10.81	10.06	10.10	10.70	11.43	11.99	40	3.52	3.42	3.55	3.74	3.87	3.94
	34	14.12	13.04	12.94	13.62	14.59	15.43	42	4.32	4.16	4.30	4.55	4.74	4.86
	36	18.20	16.69	16.41	17.12	18.33	19.52	44	5.26	5.01	5.16	5.48	5.75	5.92
	38	23.15	21.14	20.61	21.31	22.74	24.31	46	6.36	6.01	6.14	6.53	6.90	7.14
	40	29.11	26.49	25.65	26.29	27.91	29.90	48	7.64	7.16	7.27	7.73	8.21	8.55

* From "AASHO Interim Guide for the Design of Rigid Pavement Structures." AASHO Committee on Design, February 1962.

tions. A manual of instructions for making the surveys and preparing the data will be furnished each State by the Bureau of Public Roads.

Briefly, the pavement evaluation survey will consist of five major parts:

1. Determination of total lane mileage by thickness, road type, and pavement type (rigid, flexible, or composite) on the Federal-aid highway systems, ranked in four categories of surface structure condition, and in five ADT groups. Figure 7 is a flow diagram showing steps involved in this operation.

2. Conversion of average traffic volume in

TABLE 2

FLEXIBLE PAVEMENT EQUIVALENCE FACTORS*
(W_{t_a} = 18-Kip Single-Axle Load)

	SINGLE AXLE						TANDEM AXLE						
	Gross Axle Load, kips	Structural Number, $\overline{SN}$						Gross Axle Load, kips	Structural Number, $\overline{SN}$					
		1	2	3	4	5	6		1	2	3	4	6	8
$p_t = 2.0$	2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	10	0.01	0.01	0.01	0.01	0.01	0.01
	4	0.002	0.003	0.002	0.002	0.002	0.002	12	0.01	0.02	0.02	0.01	0.01	0.01
	6	0.01	0.01	0.01	0.01	0.01	0.01	14	0.02	0.03	0.03	0.03	0.02	0.02
	8	0.03	0.04	0.04	0.03	0.03	0.03	16	0.04	0.05	0.05	0.05	0.04	0.04
	10	0.08	0.08	0.09	0.08	0.08	0.08	18	0.07	0.08	0.08	0.08	0.07	0.07
	12	0.16	0.18	0.19	0.18	0.17	0.17	20	0.10	0.12	0.12	0.12	0.11	0.10
	14	0.32	0.34	0.35	0.35	0.34	0.33	22	0.16	0.17	0.18	0.17	0.16	0.16
	16	0.59	0.60	0.61	0.61	0.60	0.60	24	0.23	0.24	0.26	0.25	0.24	0.23
	18	1.00	1.00	1.00	1.00	1.00	1.00	26	0.32	0.34	0.36	0.35	0.34	0.33
	20	1.61	1.59	1.56	1.55	1.57	1.60	28	0.45	0.46	0.49	0.48	0.47	0.46
	22	2.49	2.44	2.35	2.31	2.35	2.41	30	0.61	0.62	0.65	0.64	0.63	0.62
	24	3.71	3.62	3.43	3.33	3.40	3.51	32	0.81	0.82	0.84	0.84	0.83	0.82
	26	5.36	5.21	4.88	4.68	4.77	4.96	34	1.06	1.07	1.08	1.08	1.08	1.07
	28	7.54	7.31	6.78	6.42	6.52	6.83	36	1.38	1.38	1.38	1.38	1.38	1.38
	30	10.38	10.03	9.24	8.65	8.73	9.17	38	1.76	1.75	1.73	1.72	1.73	1.74
	32	14.00	13.51	12.37	11.46	11.48	12.17	40	2.22	2.19	2.15	2.13	2.16	2.18
	34	18.55	17.87	16.30	14.97	14.87	15.63	42	2.77	2.73	2.64	2.62	2.66	2.70
	36	24.20	23.30	21.16	19.28	19.02	19.93	44	3.42	3.36	3.23	3.18	3.24	3.31
	38	31.14	29.95	27.12	24.55	24.03	25.10	46	4.20	4.11	3.92	3.83	3.91	4.02
	40	39.57	38.02	34.34	30.92	30.04	31.25	48	5.10	4.98	4.72	4.58	4.68	4.83
	Gross Axle Load, kips	Structural Number, $\overline{SN}$						Gross Axle Load, kips	Structural Number, $\overline{SN}$					
		1	2	3	4	5	6		1	2	3	4	5	6
$p_t = 2.5$	2	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002	10	0.01	0.01	0.01	0.01	0.01	0.01
	4	0.003	0.004	0.004	0.003	0.003	0.002	12	0.02	0.02	0.02	0.02	0.01	0.01
	6	0.01	0.02	0.02	0.01	0.01	0.01	14	0.03	0.04	0.04	0.03	0.03	0.02
	8	0.03	0.05	0.05	0.04	0.03	0.03	16	0.04	0.07	0.07	0.06	0.05	0.04
	10	0.08	0.10	0.12	0.10	0.09	0.08	18	0.07	0.10	0.11	0.09	0.08	0.07
	12	0.17	0.20	0.23	0.21	0.19	0.18	20	0.11	0.14	0.16	0.14	0.12	0.11
	14	0.33	0.36	0.40	0.39	0.36	0.34	22	0.16	0.20	0.23	0.21	0.18	0.17
	16	0.59	0.61	0.65	0.65	0.62	0.61	24	0.23	0.27	0.31	0.29	0.26	0.24
	18	1.00	1.00	1.00	1.00	1.00	1.00	26	0.33	0.37	0.42	0.40	0.36	0.34
	20	1.61	1.57	1.49	1.47	1.51	1.55	28	0.45	0.49	0.55	0.53	0.50	0.47
	22	2.48	2.38	2.17	2.09	2.18	2.30	30	0.61	0.65	0.70	0.70	0.66	0.63
	24	3.69	3.49	3.09	2.89	3.03	3.27	32	0.81	0.84	0.89	0.89	0.86	0.83
	26	5.33	4.99	4.31	3.91	4.09	4.48	34	1.06	1.08	1.11	1.11	1.09	1.08
	28	7.49	6.98	5.90	5.21	5.39	5.98	36	1.38	1.38	1.38	1.38	1.38	1.38
	30	10.31	9.55	7.94	6.83	6.97	7.79	38	1.75	1.73	1.69	1.68	1.70	1.73
	32	13.90	12.82	10.52	8.85	8.88	9.95	40	2.21	2.16	2.06	2.03	2.08	2.14
	34	18.41	16.94	13.74	11.34	11.18	12.51	42	2.76	2.67	2.49	2.43	2.51	2.61
	36	24.02	22.04	17.73	14.38	13.93	15.50	44	3.41	3.27	2.99	2.88	3.00	3.16
	38	30.90	28.30	22.61	18.06	17.20	18.98	46	4.18	3.98	3.58	3.40	3.55	3.79
	40	39.26	35.89	28.51	22.50	21.08	23.04	48	5.08	4.80	4.25	3.98	4.17	4.49

* From "AASHO Interim Guide for the Design of Flexible Pavement Structures." AASHO Committee on Design, February 1962.

selected ADT groups to equivalent 18-kip single-axle loads.

3. Determination of remaining life expectancy for existing lane mileage determined under Part 1 from its present Serviceability Index to a selected terminal Serviceability Index under various conditions.

4. Determination of the number of miles of resurfacing required on a 5-yr basis under (a) present axle-load limits, and (b) at some higher axle-load limit.

5. Determination of comparative cost of the resurfacing program under conditions set forth in Part 4.

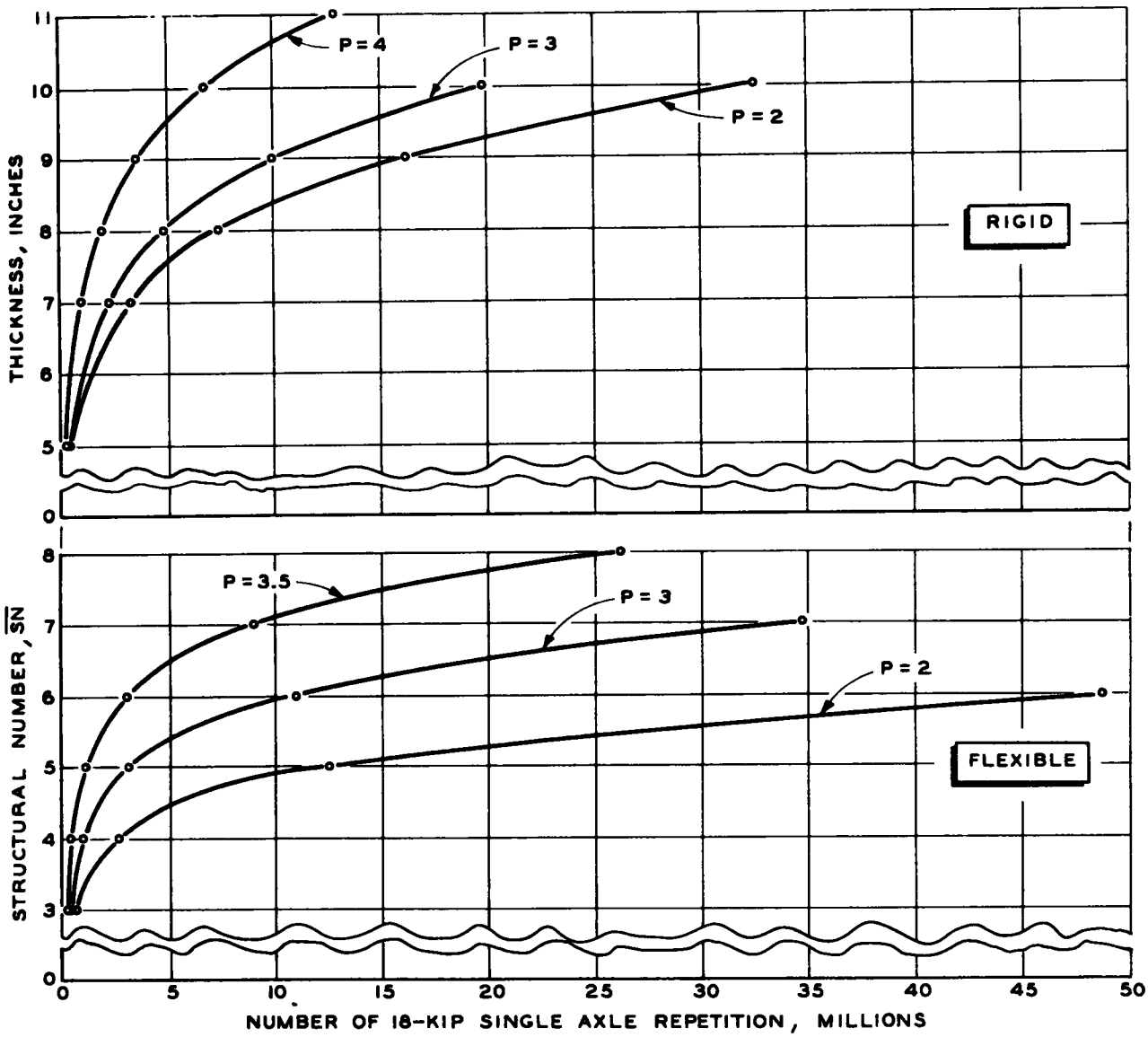

Figure 5. Relation between pavement thickness design and 18-kip single-axle load frequency (p = terminal serviceability index).

TABLE 3

Single Axle (kips)	Equivalent Tandem Axle (kips)
18	31
20	35
22	37
24	42
30	53

TABLE 4

PAVEMENT SURFACE CATEGORIES

Adjective Rating	Serviceability Index
Very good	4 to 5
Good	3 to 4
Fair	2 to 3
Poor	0 to 2

Pavement Surface Condition

The pavement surface categories to be used in the survey are given in Table 4. Since a pavement with a Serviceability Index of 2 or less may be considered ready for resurfacing, the adjective rating "very poor" as shown in Figure 2a has been combined with "poor" in this discussion. In determining the Serviceability Index, the State highway authorities will be permitted to use personal experience and

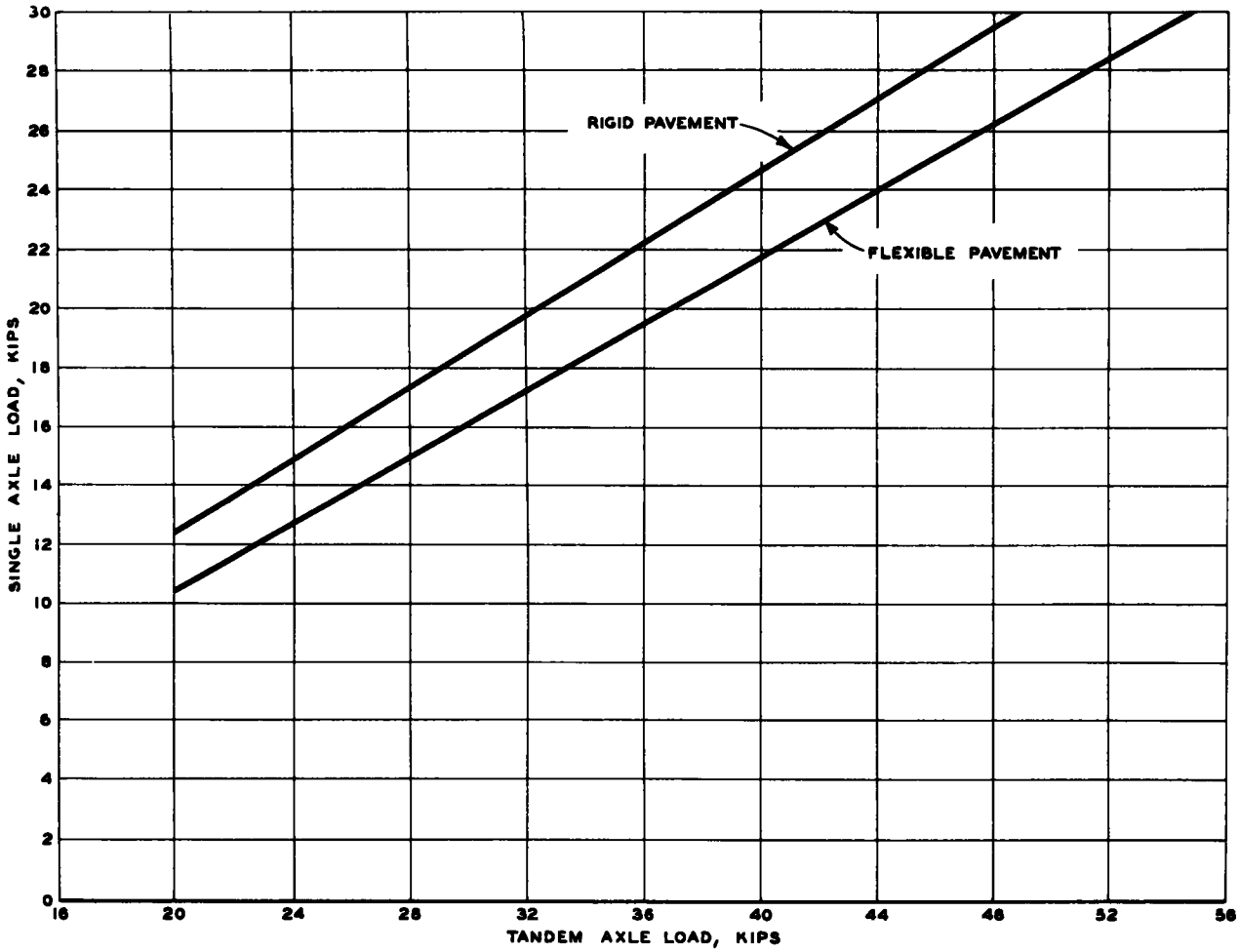

Figure 6. Single- and tandem-axle load equivalence at terminal serviceability of 2.5.

judgment, and any available information regarding pavement condition (such as sufficiency ratings and road life studies) which will provide means of approximating the Serviceability Index of existing pavements with enough accuracy for this investigation.

Serviceability Indices

Average Serviceability Index values, based on AASHO Road Test experience and on a subsequent nationwide survey conducted in Fall and Winter of 1961-62 by the Bureau of Public Roads, are given in Table 5.

Directional Traffic

From the national averages, the numbers of directional passenger and commercial vehicles using the outside lane for each of the three listed road types may be estimated as in Table 6, where *A* equals the percentage of vehicles (passenger or commercial) using the outside lane.

TABLE 5

AVERAGE SERVICEABILITY INDEX VALUES

Highways Surveyed	Serviceability Indices for Pavements Ready for Resurfacing (Based on BPR Survey)		Pavement Type	Serviceability Indices Averages (Based on AASHO Road Test)	
	Rigid	Flexible		New	Terminal
Major	2.2	2.1	Rigid	4.5	2.5
Lesser	—	1.8	Flexible	4.2	2.0

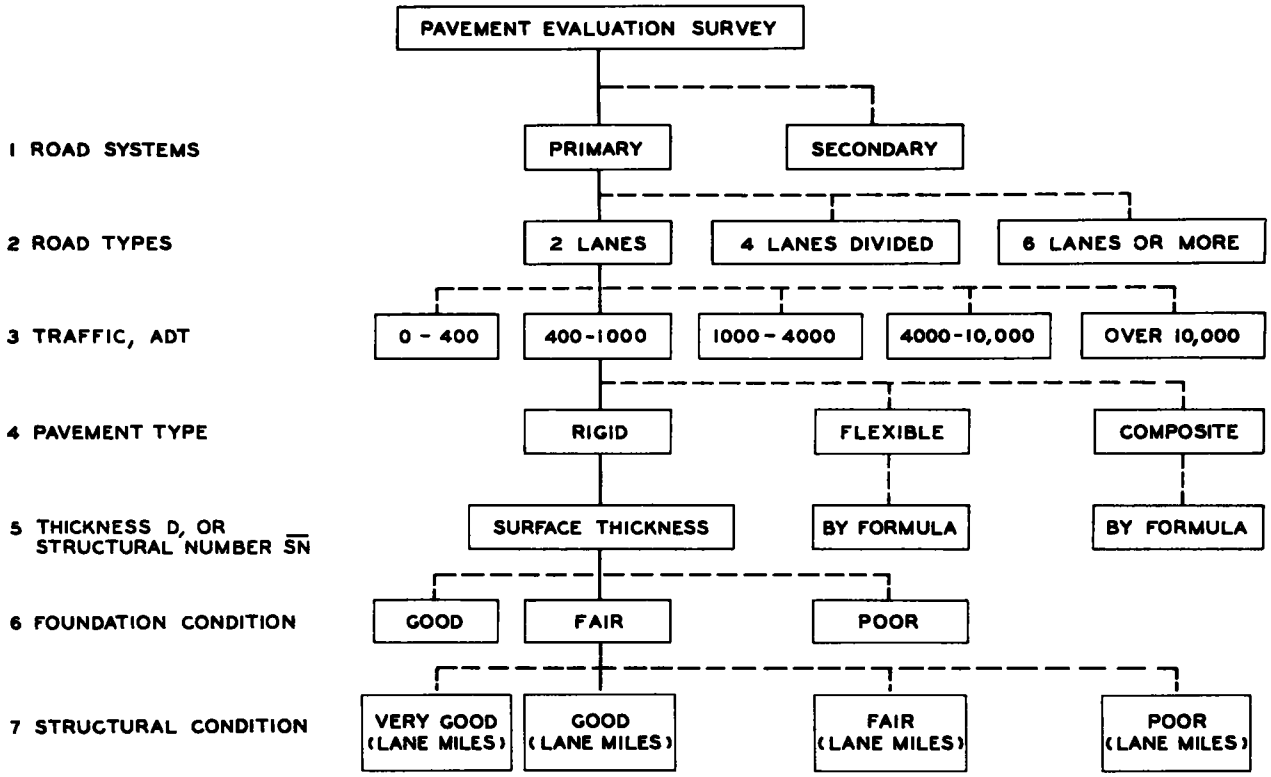

Figure 7. Flow chart indicating steps for estimating total mileage of pavement in various conditions.

TABLE 6

Road Type	Passenger	Commercial
2 lanes	$\frac{ADT}{2}$ (1 − % commercial)	$\frac{ADT}{2}$ × % commercial
4 lanes	$\frac{ADT}{2}$ (1 − % commercial) × A	$\frac{ADT}{2}$ × % commercial × A
6 lanes	$\frac{ADT}{2}$ (1 − % commercial) × A	$\frac{ADT}{2}$ × % commercial × A

Reducing Traffic Volume to Equivalent 18-Kip Single-Axle Loads

The values for total daily mixed-axle applications may be further resolved into equivalent daily and annual 18-kip single-axle applications, by simply multiplying the applications in each weight class category by the corresponding 18-kip single-axle load factor obtained from Tables 1 or 2, depending on the pavement type involved.

To simplify the work, average equivalence factor values (Table 7) may be used, representing averages from the data in Tables 1 and 2 for a selected Serviceability Index. This relationship is represented graphically in Figure 8, based on a Terminal Index of 2.2. Then, the average number of 18-kip single-axle loads per outside lane for each ADT class may be determined for use in the pavement evaluation survey.

Prepared graphs similar to the example in Figure 9 provide a rapid means of estimating the daily number of equivalent 18-kip single axles, when the average daily number of mixed axles and percentage of commercial traffic are known.

Calculating Remaining Service Life

The AASHO Road Test equations relating pavement performance to design and axle load may be extended to approximate the remaining service life of existing pavements under the following conditions:

1. When ADT does not change.
2. When ADT increases.
3. When axle-load limits are increased.
4. When both ADT and axle-load limits are increased.

TABLE 7

TRAFFIC COMPOSITION AND EQUIVALENT 18-KIP AXLE LOADS

(Based on Terminal Serviceability Index of 2.2)

	Axle Load (kips)	Equivalent Factor for 18-Kip Single-Axle Load *
Autos	2	0.0002
Single Axle, Commercial		
	0 — 3	0.0002
	3 — 5	0.002
	5 — 7	0.011
	7 — 9	0.035
	9 — 10	0.088
	10 — 13	0.188
	13 — 15	0.354
	15 — 17	0.613
	17 — 19	1.000
	19 — 21	1.550
	21 — 23	2.305
	23 — 25	3.316
	Over 25	4.634
Tandem Axle, Commercial		
	0 — 6	0.001
	6 — 10	0.007
	10 — 14	0.025
	14 — 18	0.071
	18 — 22	0.177
	22 — 26	0.376
	26 — 30	0.715
	30 — 34	1.242
	34 — 38	1.823
	38 — 42	3.117
	42 — 46	4.613
	Over 46	6.594

* Based on average equivalence factors in both rigid and flexible pavement.

The structural number $\overline{SN}$ of flexible pavement, or the concrete thickness D (in inches), and the 18-kip single-axle load frequency may be used, in conjunction with the appropriate Road Test equation or a graph similar to Figure 10, to estimate the number of 18-kip single-axle load applications sufficient to reduce the Serviceability Index to:

1. The value associated with its present condition (very good, good, fair, poor).
2. The value at which pavement is ready for resurfacing or reconstruction.

The difference between these two values is the remaining service life measured in terms of the number of 18-kip single-axle load applications. Dividing this value by the average annual traffic load expressed as equivalent 18-kip single-axle applications will give the years of life remaining until the pavement should be resurfaced or retired, if the axle-load limit or traffic frequency does not change. Corresponding calculations using the axle-load composition forecast for other axle-load limits or frequencies will give the years of life remaining under such conditions.

Resurfaced and Composite Pavements

It is considered reasonable to use the basic AASHO flexible pavement equation with the value of $\overline{SN}$ in the equation determined as shown in Appendix H to predict the performance of resurfaced and composite pavements.

The number of 18-kip single-axle applications sufficient to reduce the Serviceability Index of a resurfaced or composite pavement from an original value to a selected terminal Serviceability Index can be computed. This value can then be used in estimating remaining life in terms of 18-kip applications.

Correction Factors

It is recognized that the Road Test findings are associated with the general conditions including soil, time, and climate which prevailed at the Road Test site. Correction factors for these conditions will be suggested for use in modifying the AASHO Road Test Equation to fit conditions in other parts of the United States.

Pavement Life Summary

From information derived about existing structural conditions of the various highways in the selected ADT classes, for any time interval it is possible to estimate the miles of resurfacing or reconstruction necessary for each road type existing in the highway system under present axle-load limits, or for any future planned or anticipated changes in axle-load limits or frequencies, and for different ADT classifications. This information is actually a compilation of the remaining years of pavement life for each highway system by road type.

For each road type, a weighted average pavement life is estimated by multiplying the mileage value by its average life (for example, 2.5, 7.5, 12.5, 17.5, and 22.5 yr) and dividing the sum of the products by the total miles. Comparison of these average pavement life values for the different axle-load limits will serve as a basis for evaluating the load-carrying capacity of the existing highway system.

Calculated Expenditures to Meet Changes

The cost of a reconditioning program to meet given traffic conditions can now be estimated by applying the unit cost of the resurfacing material, the thickness customarily used for a road type, and the ADT class to the miles of resurfacing.

Analysis and Findings

Each State will receive a guide manual from the Bureau of Public Roads describing in detail the various steps necessary to make the pavement evaluation study described above.

The data resulting from the nationwide pave-

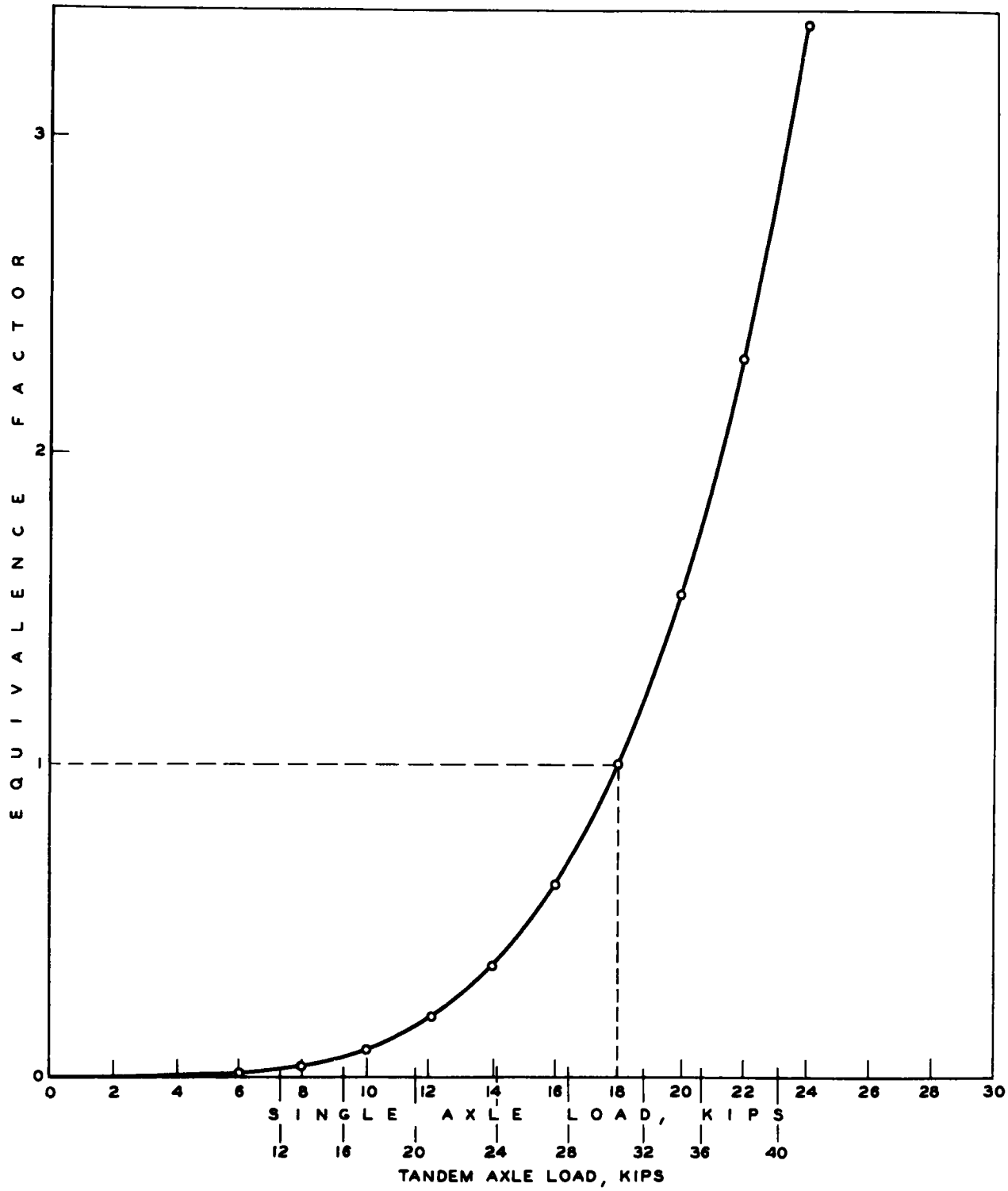

Figure 8. Relation between axle loads and equivalence factors, based on terminal serviceability index of 2.2, and on average equivalence factors for both rigid and flexible pavement.

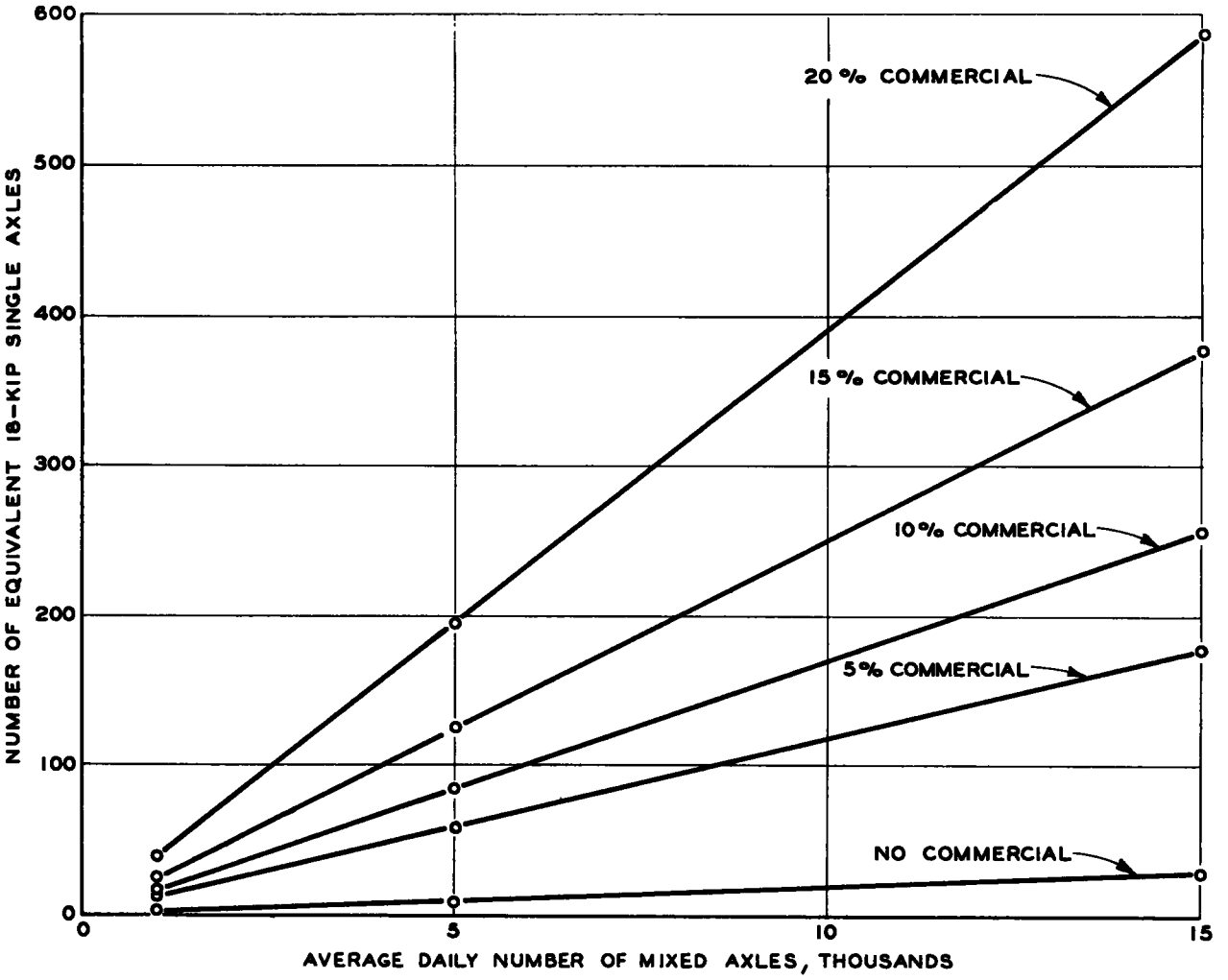

Figure 9. Example showing relation between average total daily axles and equivalent 18-kip single axles, with curves based on national average traffic distribution.

ment evaluation survey will be compiled and analyzed by the staff of Bureau of Public Roads. The Bureau and the AASHO Committee on Highway Transport will use certain findings from the evaluation survey as supporting material for recommending axle load limits as required in their respective assignments.

ACKNOWLEDGMENTS

The authors are indebted to G. P. St. Clair, Director, Highway Cost Allocation Study, Bureau of Public Roads, and his staff for preparing a Guide Manual to be used by the States in evaluating the load-carrying capacity of their respective highway plants. This paper includes a fraction of the information contained in this work.

The authors are also grateful to Paul Irick, Research Statistician, Highway Research Board, and W. E. Chastain, Engineer of Physical Research, Illinois Department of Highways, for their complete review and comments, and to Fred Copple, Physical Research Engineer, Michigan State Highway Department, for assistance on various phases of the paper.

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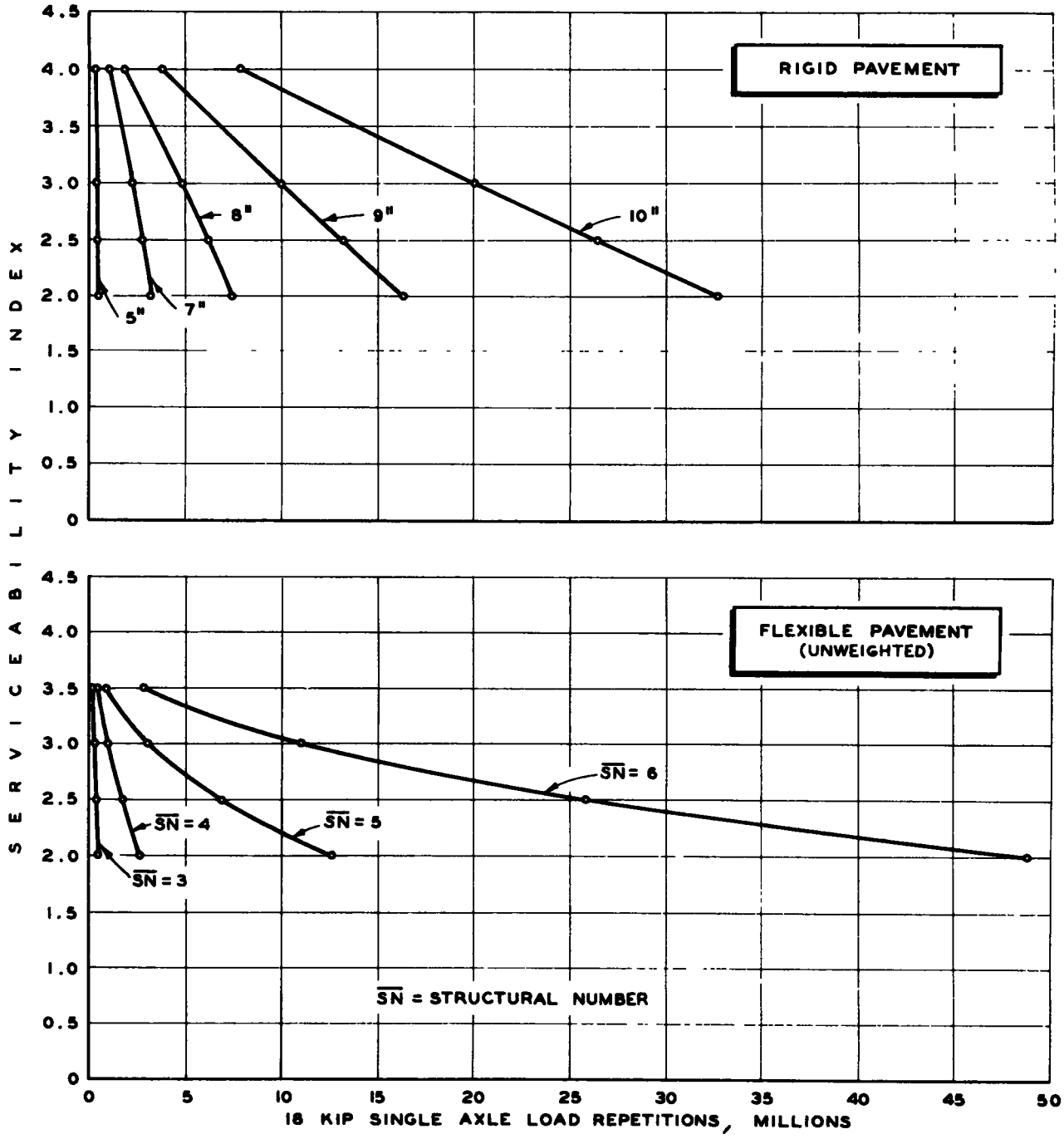

Figure 10. Relation among serviceability index, structural thickness, and repetitions of 18-kip axle loads.

APPENDIX A

DEFINITION OF TERMS FOR PSI EQUATIONS

Rigid Pavement (Eq. 1)

$\overline{SV}$ = average slope variance in both wheelpaths as measured by the AASHO profilometer.

C = major cracking in linear feet per 1,000 sq ft of pavement area. Major cracks are sealed cracks and those which are spalled to a width of ¼ in. for at least half of their length. Measurement is made on the longitudinal or transverse projection of the crack, whichever is greater.

P = bituminous patching in square feet per 1,000 sq ft of pavement area. Area cracking which is awaiting maintenance may also be included in this category.

Flexible Pavement (Eq. 2)

$\overline{SV}$ = average slope variance obtained in both wheelpaths as obtained from the AASHO profilometer.

C = area cracking in square feet per 1,000 sq ft of surface area, which has progressed into a definite pattern joined in both directions.

P = repair of the surface either by skin patching or deep patching in square feet per 1,000 sq ft of surface area.

$\overline{RD}$ = rut depth in inches measured at the center of a 4-ft span in the deepest part of the rut. This is obtained by averaging 40 to 50 evenly spaced samples for a 1,000-ft section.

Eqs. 1 and 2 can be modified for local use by correlating local roughometers with AASHO profilometer, and thereby substituting local data for the term $\log(1+\overline{SV})$.

DERIVATION OF PSI OBTAINED USING MICHIGAN ROUGHOMETER

Rigid Pavement

Original PSI equation:

$$PSI_{221} = 5\ 41 - 1\ 80 \log(1 + SV) - 0\ 09\sqrt{C + P} \qquad (1)$$

Correlation between $\log(1 + SV)$ and $\log M_1R_{20}$:

$$\log(1 + SV) = 2\ 66 \log M_1R_{20} - 4\ 89$$

Substituting into original PSI equation:

$$PSI_{922} = 5\ 41 - 1\ 80\ (2\ 66 \log M_1R_{20} - 4\ 89) - 0\ 9\sqrt{C + P}$$
$$= 5\ 41 - 4\ 79 \log M_1R_{20} + 8\ 80 - 0\ 09\sqrt{C + P}$$
$$PSI_{922} = 14\ 21 - 4.79 \log M_1R_{20} - 0\ 09\sqrt{C + P} \qquad *(1a)$$

Flexible Pavement

Original PSI Equation (involving rut depth):

$$PSI_{121} = 5\ 03 - 1\ 91 \log(1 + SV) - 0\ 01\sqrt{C + P} - 1\ 38\ (\overline{RD})^2 \qquad (2)$$

Correlation equation:

$$\log(1 + SV) = 2\ 53 \log M_1R_{20} - 4\ 6$$

Substituting into original PSI equation:

$$PSI_{923} = 5\ 03 - 1\ 91\ (2.53 \log M_1R_{20} - 4\ 6) - 0\ 01\sqrt{C + P} - 1\ 38\ (\overline{RD})^2$$
$$= 5\ 03 - 4\ 83 \log M_1R_{20} + 8\ 79 - 0\ 01\sqrt{C + P} - 1.38\ (\overline{RD})^2$$
$$PSI_{923} = 13\ 82 - 4\ 83 \log M_1R_{20} - 0\ 01\sqrt{C + P} - 1\ 38\ (\overline{RD})^2 \qquad *(2a)$$

* PSI obtained using Michigan roughometer.

APPENDIX B

BASIC AASHO ROAD TEST EQUATION—RIGID PAVEMENT

$$G_t = \log \frac{C_0 - p}{C_0 - 1\ 5} = \beta (\log W_t - \log \rho) \tag{3}$$

in which:

G_t = a function (the logarithm) of the ratio of loss in serviceability at time t to the total potential loss taken to the point where $p = 1.5$ (the point at which pavement sections were removed from the Road Test).

C_0 = initial serviceability index of pavement (equal to 4 5 on test road).

p = serviceability index at end of time period.

β = a function of design and load variables that influences the shape of the p vs W_t serviceability curve.

W_t = axle load applications at time t.

ρ = a function of design and load variables that denotes the expected number of axle load applications to a serviceability index of 1.5.

The equations for ρ and β in log form are

$$\log \rho = 5\ 85 + 7\ 35 \log (D + 1) - 4\ 62 \log (L_1 + L_2) + 3\ 28 \log L_2 \tag{3a}$$

and

$$\log (\beta - 1\ 0) = \log 3\ 63 + 5\ 20 \log (L_1 + L_2) - 8\ 46 \log (D + 1) - 3\ 52 \log L_2 \tag{3b}$$

in which:

L_1 = load on one single-load axle or on one tandem-axle set, kips;

L_2 = axle code, 1 for single; 2 for tandem; and

D = thickness of concrete slabs, in.

APPENDIX C

BASIC AASHO ROAD TEST EQUATION—FLEXIBLE PAVEMENT

The general AASHO Road Test equation is:

$$G_t = \beta (\log W_t - \log \rho)$$

in which:

G_t = a function (the logarithm) of the ratio of loss in serviceability at time t to the total potential loss taken to a point where $p_t = 1\ 5$.

β = a function of design and load variables that influences the shape of the p vs W serviceability curve.

W_t = weighted traffic factor.

ρ = a function of design and load variables that denotes the expected number of axle load applications to a serviceability index of 1 5.

p_t = serviceability index at end of time t.

In the AASHO Road Test, the terms β and ρ were found for weighted axle load applications, to have the following relationships to load and pavement factors.

$$\beta = 0.40 + \frac{0\ 081\ (L_1 + L_2)^{3\ 23}}{(\overline{SN} + 1)^{5.19}\ L_2^{3\ 23}} \tag{3c}$$

and

$$\log \rho = 5\ 93 + 9.36 \log (\overline{SN} + 1) - 4\ 79 \log (L_1 + L_2) + 4\ 33 \log L_2 \tag{3d}$$

where:

L_1 = load on one single-load axle or on one tandem-axle set, kips;
L_2 = axle code, 1 for single; 2 for tandem; and
$\overline{SN}$ = structural number (a measure of pavement thickness and strength).

Since the equations for both β and ρ contain the terms L_1, L_2 and $\overline{SN}$, the solution of the general AASHO Road Test equation becomes quite involved, particularly when solving for $\overline{SN}$. This is the factor normally sought in the design of pavement structures. However, the solution of the equation can be simplified by expressing all load factors in terms of a common denominator. In this guide the load factors have been resolved in terms of the 18,000-lb single-axle load. To accomplish this, the following steps were taken.

The general equation may be written:

$$\log W_t = \log \rho + G_t/\beta \tag{4}$$

when L_1 = 18 kips, L_2 = 1 and if W_t represents weighted application obtained through the use of the seasonal weighting function, Eq. 3c becomes

$$\beta = 0\ 40 + \frac{0\ 081\ (18 + 1)^{3.23}}{(\overline{SN} + 1)^{5\ 19}} = 0\ 40 + \frac{1{,}094}{(\overline{SN} + 1)^{5.19}}$$

and Eq. 3d becomes

$$\log \rho = 5.93 + 9\ 36 \log (\overline{SN} + 1) - 4\ 79 \log (18 + 1)$$
$$= 9\ 36 \log (\overline{SN} + 1) - 0.20$$

in which:

$\overline{SN}$ = $0\ 44\ D_1 + 0.14\ D_2 + 0.11\ D_3$;
D_1 = surface thickness, in.;
D_2 = base thickness, in.; and
D_3 = subbase thickness, in.

Inserting expressions for β and $\log \rho$ in Eq. 4,

$$\log W_{t_{18}} = 9\ 36 \log (\overline{SN} + 1) - 0.20 + \frac{G_t}{0.40 + \dfrac{1{,}094}{(\overline{SN} + 1)^{5.19}}} \tag{4a}$$

APPENDIX D

DETERMINATION OF EQUIVALENCE FACTORS FOR RIGID PAVEMENT

(From AASHO Interim Guide for the Design of Rigid Pavement Structures)

The AASHO Road Test equation may be written:

$$\log W_t = \log \rho + G_t/\beta \tag{4}$$

or

$$\log W_t = 5\ 85 + 7\ 35 \log (D + 1) - 4\ 62 \log (L_1 + L_2) + 3.28 \log L_2 + G_t/\beta \tag{4a}$$

When $L_1 = 18$ and $L_2 = 1$ (single axle),

$$\log W_{t_{18}} = 5\ 85 + 7\ 35 \log (D + 1) - 4\ 62 \log (18 + 1) + G_t/\beta_{18}$$

Also, when $L_1 = y$ and $L_2 = 1$,

$$\log W_{t_y} = 5\ 85 + 7.35 \log (D + 1) - 4\ 62 \log (y + 1) + G_t/\beta_y$$

Subtracting $\log W_{t_y}$ from $\log W_{t_{18}}$, for single axles,

$$\log W_{t_{18}}/W_{t_y} = 4\ 62 \log (y + 1) - 4\ 62 \log (18 + 1) + G_t/\beta_{18} - G_t/\beta_y \quad (4b)$$

Similarly, when $L_1 = y$ and $L_2 = 2$ (tandem axle),

$$\log W_{t_y} = 5\ 85 + 7\ 35 \cdot \log (D + 1) - 4\ 62 \log (y + 2) + 3\ 28 \log 2 + G_t/\beta_y$$

Subtracting $\log W_{t_y}$ for tandem axles from $\log W_{t_{18}}$, for tandem axles,

$$\log W_{t_{18}}/W_{t_y} = 4.62 \log (y + 2) - 4\ 62 \log (18 + 1) - 3\ 28 \log 2 + G_t/\beta_{18} - G_t/\beta_y \quad (4c)$$

The ratio of $W_{t_{18}}$ to W_{t_y} expresses the relationship of the 18,000-lb single-axle load to any other axle load y, single or tandem. The ratio becomes the equivalent factor and may be evaluated by solving the equations for different values of y. Since ρ varies with D and L_y a series of equivalence factors is obtained for each value of D.

APPENDIX E

DETERMINATION OF EQUIVALENCE FACTORS FOR FLEXIBLE PAVEMENTS

(From AASHO Interim Guide for the Design of Flexible Pavement Structures)

The AASHO Road Test equation may be written:

$$\log W_t = \log \rho + G_t/\beta \quad (4)$$

or

$$\log W_t = 5\ 93 + 9\ 36 \log (\overline{SN} + 1) - 4\ 79 \log (L_1 + L_2) + 4\ 33 \log L_2 + G_t/\beta \quad (4d)$$

When $L_1 = 18$ and $L_2 = 1$ (single axles),

$$\log W_{t_{18}} = 5\ 93 + 9\ 36 \log (\overline{SN} + 1) - 4\ 79 \log (18 + 1) + G_t/\beta_{18}$$

When $L_1 = y$ and $L_2 = 1$ (single axles),

$$\log W_{t_y} = 5\ 93 + 9\ 36 \log (\overline{SN} + 1) - 4\ 79 \log (L_y + 1) + G_t/\beta_y$$

Subtracting $\log W_{t_y}$ from $W_{t_{18}}$, for single axles,

$$\log W_{t_{18}}/W_{t_y} = 4\ 79 \log (L_y + 1) - 4.79 \log (18 + 1) + G_t/\beta_{18} - G_t/\beta_y \quad (4e)$$

Similarly, when $L_1 = y$ and $L_2 = 2$ (tandem axles),

$$\log W_{t_y} = 5\ 93 + 9\ 36 \log (\overline{SN} + 1) - 4\ 79 \log (L_y + 2) + 4\ 33 \log 2 + G_t/\beta_y$$

Subtracting W_{t_y} for tandem axles from $W_{t_{18}}$, for tandem axles,

$$\log W_{t_{18}}/W_{t_y} = 4.79 \log (L_y + 2) - 4\ 79 \log (18 + 1) - 4\ 33 \log 2 + G_t/\beta_{18} - G_t/\beta_y \qquad (4f)$$

The ratio between $W_{t_{18}}$ and W_{t_y} expresses the relationship between the 18,000-lb single-axle load and any other axle load y, single or tandem. The ratio becomes the equivalence factor and may be evaluated by solving the equations for different values of y. Since ρ varies with $\overline{SN}$ and L_y (see Appendix C), a series of equivalence factors is obtained for each value of $\overline{SN}$.

APPENDIX F

AASHO ROAD TEST EQUATION FOR PREDICTING RIGID PAVEMENT PERFORMANCE AS A FUNCTION OF 18-KIP SINGLE-AXLE LOADS AND DESIGN

Basic AASHO Road Test equation for relating performance to design and load is

$$\log W_t = \log \rho + \frac{\log \dfrac{4.5 - p}{3}}{\beta} \qquad (4g)$$

in which:

W_t = Number of applications of axle load (L_1) required to reduce serviceability index of pavement to specified value (p);

$\rho = \dfrac{10^{5\ 85} (D + 1)^{7.35} L_2^{3\ 28}}{(L_1 + L_2)^{4.62}}$;

$\beta = 1 + \dfrac{3.63 (L_1 + L_2)^{5\ 20}}{(D + 1)^{8\ 46} L_2^{3.52}}$;

D = pavement slab thickness, in inches;

L_1 = axle load, in kips; and

L_2 = 1 for single axles, 2 for tandem axles.

Thus, for 18-kip single axles:

$$\rho = \frac{10^{5\ 85} (D + 1)^{7\ 35} (1)^{3\ 28}}{(18 + 1)^{4.62}}$$

$$\log \rho = 5\ 85 + 7.35 \log (D + 1) - 4.62 \log 19$$
$$= 7\ 35 \log (D + 1) - 0\ 06$$

$$\beta = 1 + \frac{3.63 (18 + 1)^{5.20}}{(D + 1)^{8.46} (1)^{3.52}}$$

$$\beta = 1 + \frac{16\ 2 \times 10^6}{(D + 1)^{8.46}}$$

$$\log W_{18} = 7\ 35 \log (D + 1) - 0\ 06 + \frac{\log \dfrac{4.5 - p}{3}}{1 + \dfrac{16.2 \times 10^6}{(D + 1)^{8.46}}} \qquad (4h)$$

APPENDIX G

AASHO ROAD TEST EQUATION FOR PREDICTING FLEXIBLE PAVEMENT PERFORMANCE AS A FUNCTION OF UNWEIGHTED 18-KIP SINGLE-AXLE LOADS AND DESIGN

Basic AASHO Road Test equation for relating performance to design and load is

$$\log W_t = \log \rho + \frac{\log \frac{4.2 - p}{2.7}}{\beta} \tag{4i}$$

in which:

W_t = Number of unweighted applications of axle load (L_1) required to reduce serviceability index of pavement to specified value (p);

$$\rho = \frac{10^{6.16} (\overline{SN} + 1)^{8.94} L_2^{4.17}}{(L_1 + L_2)^{4.54}};$$

$$\beta = 0.4 + \frac{0.083 (L_1 + L_2)^{4.87}}{(\overline{SN} + 1)^{8.73} L_2^{4.87}};$$

L_1 = axle load, in kips;
L_2 = 1 for single axles, 2 for tandem axles;
$\overline{SN}$ = $0.37 D_1 + 0.14 D_2 + 0.10 D_3$;
D_1 = thickness of surface, in.;
D_2 = thickness of base, in.; and
D_3 = thickness of subbase, in.

Thus, for 18-kip single axles:

$$\rho = \frac{10^{6.16} (\overline{SN} + 1)^{8.94} (1)^{4.17}}{(18 + 1)^{4.54}}$$

$$\log \rho = 6.16 + 8.94 \log (\overline{SN} + 1) - 4.54 \log 19$$
$$= 0.35 + 8.94 \log (\overline{SN} + 1)$$

$$\beta = 0.4 + \frac{0.083 (19)^{4.87}}{(\overline{SN} + 1)^{8.73}}$$

$$\beta = 0.4 + \frac{14.0 \times 10^4}{(\overline{SN} + 1)^{8.73}}$$

$$\log W_{18} = 0.35 + 8.94 \log (\overline{SN} + 1) + \frac{\log \frac{4.2 - p}{2.7}}{0.4 + \frac{14.0 \times 10^4}{(\overline{SN} + 1)^{8.73}}} \tag{4j}$$

AASHO ROAD TEST EQUATION FOR PREDICTING FLEXIBLE PAVEMENT PERFORMANCE AS A FUNCTION OF WEIGHTED 18-KIP SINGLE-AXLE LOADS AND DESIGN

Basic AASHO Road Test equation for relating performance to design and load is

$$\log W_t = \log \rho + \frac{\log \frac{4.2 - p}{2.7}}{\beta} \tag{4k}$$

in which:

W_t = Number of weighted applications of axle load (L_1) required to reduce serviceability index of pavement to specified value (p);

$$\rho = \frac{10^{5.93} (\overline{SN} + 1)^{9.36} L_2^{4.33}}{(L_1 + L_2)^{4.79}};$$

$$\beta = 0.4 + \frac{0.081 (L_1 + L_2)^{3.23}}{(\overline{SN} + 1)^{5.19} L_2^{3.23}};$$

L_1 = axle load, in kips;
L_2 = 1 for single axles, 2 for tandem axles;
$\overline{SN}$ = $0.44 D_1 + 0.14 D_2 + 0.11 D_3$;
D_1 = thickness of surface, in.;
D_2 = thickness of base, in.; and
D_3 = thickness of subbase, in.

Thus, for 18-kip single axles:

$$\rho = \frac{10^{5.93} (\overline{SN} + 1)^{9.36}}{(18 + 1)^{4.79}}$$

$$\log \rho = 5.93 + 9.36 \log (\overline{SN} + 1) - 4.79 \log 19$$
$$= 9.36 \log (\overline{SN} + 1) - 0.20$$

$$\beta = 0.4 + \frac{0.081 (19)^{3.23}}{(\overline{SN} + 1)^{5.19}}$$

$$\beta = 0.4 + \frac{1{,}094}{(\overline{SN} + 1)^{5.19}}$$

$$\log W_{18} = 9.36 \log (\overline{SN} + 1) - 0.20 + \frac{\log \frac{4.2 - p}{2.7}}{0.4 + \frac{1{,}094}{(\overline{SN} + 1)^{5.19}}} \qquad (4l)$$

APPENDIX H

AASHO ROAD TEST EQUATION FOR PREDICTING PERFORMANCE OF RESURFACED AND COMPOSITE PAVEMENTS AS A FUNCTION OF 18-KIP SINGLE-AXLE LOADS AND DESIGN

$$\log W_{18} = \log \rho + G_t/\beta \qquad (4)$$

in which:

$$G_t = \log \frac{4.2 - p_t}{2.7}$$

$$\log \rho = 9.36 \log \overline{SN} = 0.20$$
$$\log (\beta - 0.4) = 3.04 - 5.19 \log \overline{SN}$$

Case I. Resurfaced Concrete Pavement

$\overline{SN}$ = $a_1D_1 + a_2D_2 + a_3D_3$
D_1 = asphaltic surface thickness in inches
D_2 = old concrete surface in inches
D_3 = subbase thickness in inches
a_1, a_2, a_3 = coefficients for common materials shown in Table 8

Case II. Resurfaced Flexible Pavement

$$\overline{SN} = a_1D_1 + a'_1D'_1 + a_2D_2 + a_3D_3$$

D_1 = new asphalt surface in inches
D'_1 = old asphalt surface in inches
D_2 = base thickness in inches
D_3 = subbase thickness in inches
a_1, a'_1, a_2, a_3 = coefficients, see Table 8

Case III. Composite Pavements

Same as Case I except coefficient (a_2) will have a value shown in Table 8 for new concrete.

TABLE 8

COEFFICIENTS FOR FLEXIBLE AND COMPOSITION PAVEMENT

Pavement Components	Other Requirements	Coefficients		
		a_1	a_2*	a_3
Surface Course				
Road mix (low stability)	Marshall stability 500–1,000	0.20	—	—
Plant mix (high stability)	Marshall stability 2,000	0.44**	—	—
Sand asphalt	Marshall stability 1,000–1,200	0.40	—	—
Base Course				
Sand gravel	CBR 20–30	—	0.07*	—
Crushed stone	CBR 105–110	—	0.14*	—
Water bound macadam		—	0.15–0.20	—
Lime treated	CBR	—	0.15–0.30	—
Sand asphalt	Marshall stability	—	0.30	—
Bituminous treated (coarse-graded)	Marshall stability	—	0.34*	—
Cement treated	650 psi 7-day compressive strength	—	0.23*	—
	400–650 psi 7-day compressive strength	—	0.20	—
	Less than 400 psi 7-day compressive strength	—	0.15	—
Old bituminous concrete surface	Undisturbed	—	0.24	—
Old bituminous concrete surface	Scarified and mixed with old base	—	0.14	—
Portland cement concrete surface				
Old		—	0.40	—
New		—	0.50	—
Subbase				
Sandy gravel	CBR 20–30	—	—	0.11**
Sand or sandy-clay		—	—	0.05–0.10

* Also a'_1 for resurfaced pavement.
** Based on AASHO Road Test Data. All other coefficients determined by assumption based on range of other values in Table 8.