Consideration of Larger Trucks in Pavement Design and Management

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ABSTRACT

Common pavement design methods (empirical and theoretical) and axle load equivalency factors are reviewed. Research on techniques for modeling new truck configurations permitted by the 1982 Surface Transportation Assistance Act is summarized. A synthesis of various pavement management system methods is provided along with two case study examples of the impact of heavy truck loads and the use of double-bottom trailers.

The Surface Transportation Assistance Act (STAA) of 1982 permitted longer, wider, and heavier trucks to operate on the Interstate system and on the primary system designated by the Secretary of Transportation. An initial step toward understanding the impact of this new traffic on roadway pavements requires a knowledge of various pavement design methods.

One of the highest priority needs in pavement design is for data to support future evaluations. In addition to the fundamental pavement structural relationships, the effects of increased loadings on pavement performance and deterioration must be investigated. Composition of the vehicular fleet, axle configurations, weight distributions, tire construction, and magnitude of tire pressures are changing rapidly and are expected to have a significant impact on the rate of highway deterioration (1).

In 1981 the Transportation Research Board prepared a proposal, which was subsequently funded by the FHWA, to do a study entitled the Strategic Transportation Research Study (STRS). The results of the TRB Committee's efforts were reported in Special Report 202, "America's Highways--Accelerating the Search for Innovation." The highway portion of the STRS is currently the Strategic Highway Research Program (SHRP). A major component of the SHRP is the study of long-term pavement performance in the United States. This ambitious undertaking is expected to continue for 20 years. Anticipated data collection includes information on loading, environment, material properties and variability, construction quality, and maintenance levels in pavement distress and performance. The objectives are to evaluate existing design methods, improve design methodologies and strategies for rehabilitation of existing pavements, and improve design equations for new and reconstructed pavements (1).

Given these considerations, the purpose of this paper is to underscore the need to provide an overview of current pavement technology. Conclusions regarding the effects of larger trucks on highway pavements can only be drawn from a perspective of the dilemma associated with establishing a long-term pavement data bank. Among the specific concerns that need to be addressed is the ability to accurately collect and maintain traffic and weight data from which the effects of loading can be determined.

Traffic is incorporated in design methods primarily through repetitions of an 18-kip equivalent single axle load (ESAL). Conversion of mixed traffic consisting of various axle loads and configurations to an 18-kip ESAL is accomplished through the use of axle load equivalency factors. The most commonly used equivalency factors are the empirical values derived by AASHTO (2). Researchers have attempted to establish theoretical equations to replicate the AASHTO values and to model axle loads and configurations not included in the original AASHTO data base. Treybig (3) has developed a set of equivalency factors for use with flexible pavement design. Sharma et al. (4) have developed equivalency factors for both flexible and rigid pavement designs.

The empirical pavement design methods reviewed in this paper are generally based on the widely used AASHO Road Test results. Boussinesq theory is the basis for elastic layer analysis and is the cornerstone of theoretical pavement design. The theoretical methods identified in this paper include those set forth by the Asphalt Institute (5), Monismith (6), Shell (7), Chevron (8), and Chua and Lytton (9).

At first it may appear that these two approaches are distinctly different. Actually, the design methods vary from pure "field" experience to detailed finite element analysis techniques. As a result it is not uncommon to obtain different answers (pavement thicknesses) from different design methods using identical input factors (2).

Pavement management systems (PMSs), which assess and predict roadway conditions and rank maintenance scheduling in priority order, are valuable tools for calculating the impact of new truck traffic characteristics. Currently implemented PMS methods, including their respective procedures for calculating traffic impact, are reviewed in this discussion.

Also reviewed are studies that investigate specific topics related to the STAA. Included are reports on oil field traffic, double bottoms, and productivity savings.

PAVEMENT DESIGN METHODS

The evaluation of the effects of heavier, wider, and longer trucks is usually accomplished through the use of standard pavement design equations. An understanding of these design methods is therefore necessary to ensure the proper assessment of the impact of these vehicles. Every rational pavement design method consists of (a) a theory to predict failure

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or a specific distress parameter or parameters, (b) an evaluation of pertinent material properties, and (c) a relationship between the magnitude of the parameter in question and failure at a specific performance level (2). Both empirical and theoretical procedures are explained.

Empirical Design Methods

AASHTO

The AASHTO pavement design procedure (2) is centered on the idea of performance as the failure criterion. Performance is defined as the ability of a pavement to satisfactorily serve traffic over a period of time. The performance of a pavement at any point in time is measured by the present serviceability index (PSI). PSI is calculated using a regression equation that considers the following distress variables: longitudinal roughness, rut depth, cracking, and patching. A damage equation is used to estimate the number of 18-kip ESALs necessary to obtain a specific value of PSI. The number of axle load applications, however, is a function of pavement structure, terminal PSI value, environmental factors, and subgrade characteristic value. The depth of each layer, the actual design, is then obtained through a regression equation that uses the structural value of the pavement.

Modifications to AASHTO Method

The AASHTO method has been implemented for many years. Alterations, proposed by Lytton et al. (10) for flexible pavements and Darter as cited by Lytton et al. (10) for jointed concrete pavements, exist with respect to the shape of the damage equation. To satisfy both the inherent boundary conditions and the experimental evidence, the equation has been revised to yield an S-shaped curve. The AASHTO design equation is of the form:

$$g = (P_i - P)/(P_i - P_t) = (N/\rho)^{\beta} \quad (1)$$

where

g = damage function that begins at 0 and becomes 1 when $P = P_t$,
P_i = initial serviceability index,
P = present serviceability index,
P_t = terminal serviceability index,
N = number of 18-kip ESALs, and
ρ, β = constants that depend on the pavement structure and the load acting on it.

The equation used by Darter for describing the long-term performance of jointed concrete pavements is of the form:

$$(P - P_f)/(P_i - P_f) = 1/(e^{\beta[(N/\rho) - 1]} + 1) \quad (2)$$

where P_f is the asymptotic value of serviceability index that the performance equation approaches.

According to Lytton, the long-term performance of flexible pavements is described by the equation:

$$(P - P_f)/(P_i - P_f) = 1 - e^{-(\rho/N)^{\beta}} \quad (3)$$

Equations 1 and 2 are compared in Figure 1 for an 8-in.-thick jointed concrete slab. Figure 2 is a comparison of Equations 1 and 3 for a flexible pavement section (seal-coated pavement) with a structural number of approximately 1.0. The graphs illustrate the more accurate modeling of field data by the S-shaped curves of Equations 2 and 3.

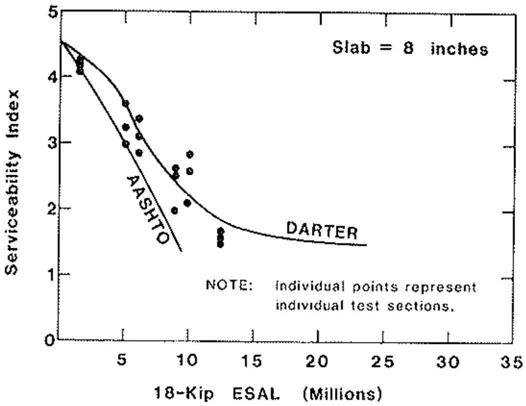

FIGURE 1 Comparison of original AASHTO performance equation, Darter's new performance equation, and actual performance data for 8-in.-thick jointed concrete slab.

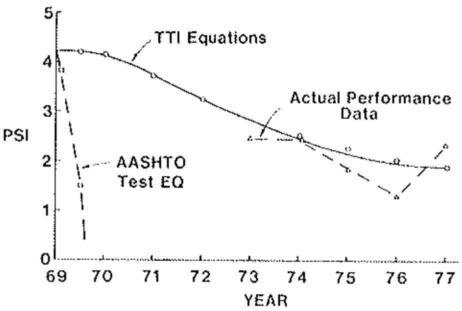

FIGURE 2 Comparison of AASHTO performance equation, Lytton's new performance equation, and actual performance data for a flexible pavement.

Theoretical Design Methods

A significant advancement in flexible pavement design was the introduction of mechanistic design methods that employ the Boussinesq theory for calculating stresses, strains, and deflections. The Boussinesq theory is only directly applicable to one-layer systems; however, adaptations of the theory are used in analyzing multilayer systems. The latest development in pavement design is the incorporation of finite element analysis. Primary distresses considered in mechanistic approaches include permanent deformation, caused by vertical compressive strain at the subgrade surface, and cracking, caused by horizontal tensile strain in the asphalt layer. Various methods, using different material characterizations and distress equations, have been proposed by the Asphalt Institute (5), Monismith (6), Shell (7), Chevron (8), and Chua and Lytton (9).

Asphalt Institute

The Asphalt Institute method for heavy wheel loads (5) incorporates a multilayer elastic theory to design full-depth asphalt pavements. The horizontal tensile strain is not considered; therefore the design is based on limiting the subgrade vertical strain. The asphalt thickness is a function of the

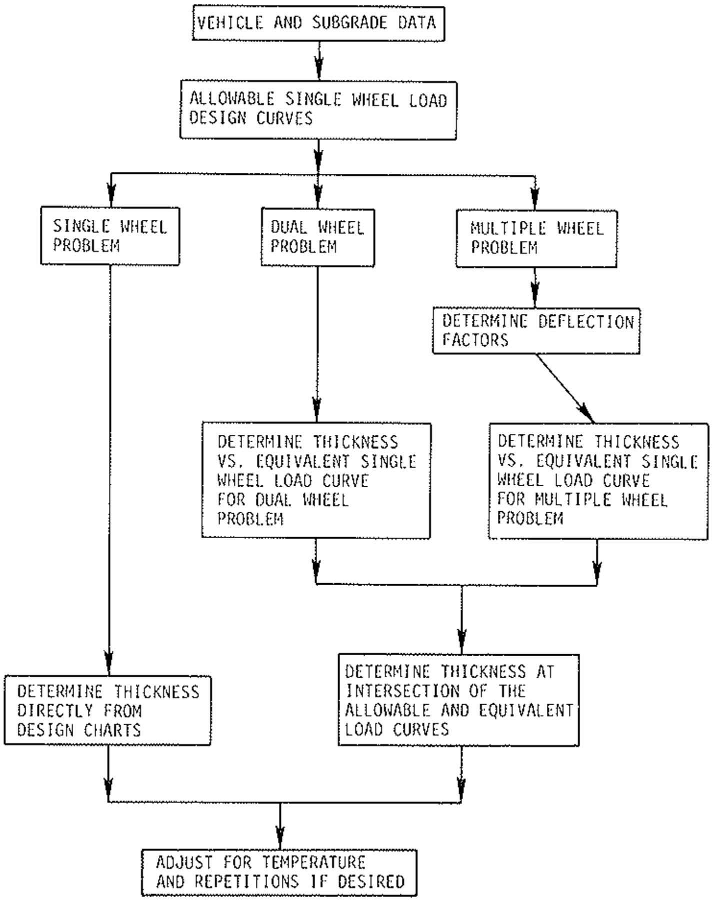

FIGURE 3 Flow diagram for the Asphalt Institute pavement design method for heavy wheel loads.

subgrade strength and the contact pressure of the load. Figure 3 shows this procedure.

Monismith

Monismith (6) incorporated the original Shell nomograph, by van der Poel, in his procedure as a means of calculating the bitumen stiffness given time of loading, temperature, and penetration index. A second nomograph allows the determination of the asphalt mix stiffness given bitumen stiffness and percentage voids in the mineral aggregate. Other inputs to the Monismith method include the average asphalt temperature, the average vehicular speed, the number of standard axles, and the subgrade elastic modulus. Figure 4 shows Monismith's methodology.

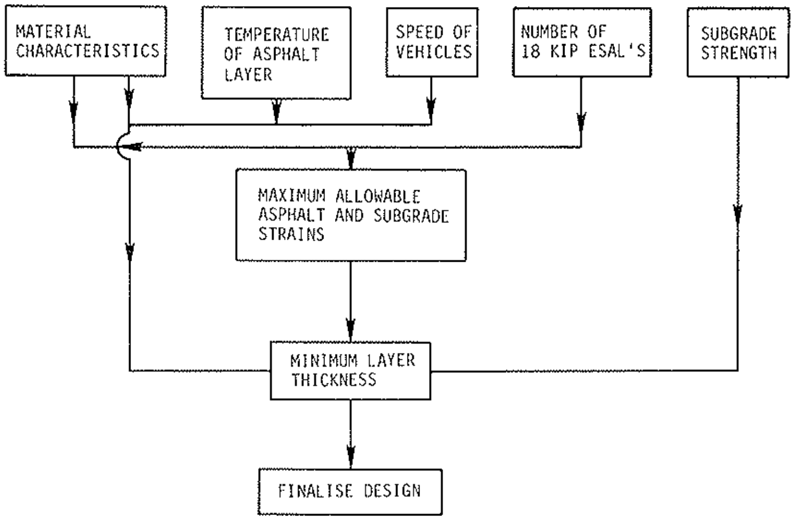

FIGURE 4 Flow diagram for the Monismith asphalt pavement design method.

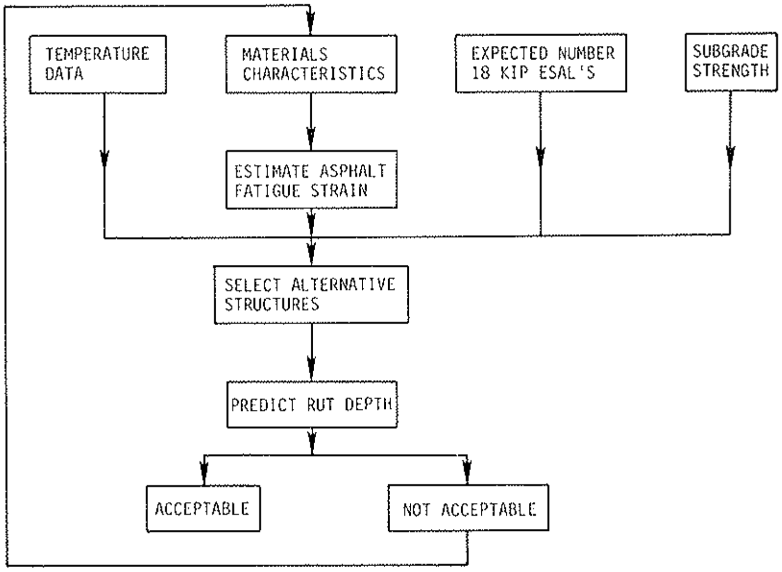

FIGURE 5 Flow diagram for the Shell asphalt pavement design method.

Shell

Extension to a three-layer linear elastic system is possible with the Shell method (7). An updated version of the Shell nomograph allows the determination of the asphalt mix stiffness given the percentage volume of mineral aggregate, the bitumen stiffness, and the percentage volume of bitumen. The BISAR computer program is used to obtain the limiting strain values and the corresponding number of 18-kip ESALs. Figure 5 shows the Shell analytical procedure.

Chevron

The Chevron method (8) uses a two-layer elastic structural model. The contributing factors include the number of 18-kip ESALs, the subgrade strength, the modulus of rupture of the asphalt, and the cure state of the asphalt. Figure 6 is a flow chart that illustrates this method.

Chua and Lytton

Chua and Lytton (9) calculate the number of passes of a specific load that causes a critical rut depth. The procedure can be used iteratively to obtain a pavement structure that will suffer a specific rut depth for given traffic conditions. The load-deflection relationship is described by a hyperbolic stress-strain curve for repetitive loading. This relationship combined with the ILLI-PAVE finite element program, which simulates deflection basins, results in rut depth histories for given pavements.

LOAD EQUIVALENCY FACTORS

The traffic factor included in each of the preceding pavement design methods is an integral component of the calculation of pavement life spans. With respect to the design of highway pavements, the traffic impact is normally incorporated through ESALs. (Figure 7). The damage effects of all vehicle types in the traffic stream are converted through the use of equivalent axle load factors to relative damage caused by a standard vehicle. The end result is the computation of the number of axle load applications that a pavement is designed to withstand in its lifetime. The values used as the equivalency factors therefore constitute a critical step in the pavement design process. Tables 1 and 2 give the equivalent axle loads calculated using the AASHTO, Monismith, and Shell equivalency procedures for the same situation. The total number of 18-kip (80-kN) ESALs in Tables 1 and 2 are AASHTO, 1,443; Monismith, 1,675; and Shell, 1,501. Monismith's values differ from those of AASHTO by +16 percent, and the Shell values differ from those of AASHTO by +4 percent.

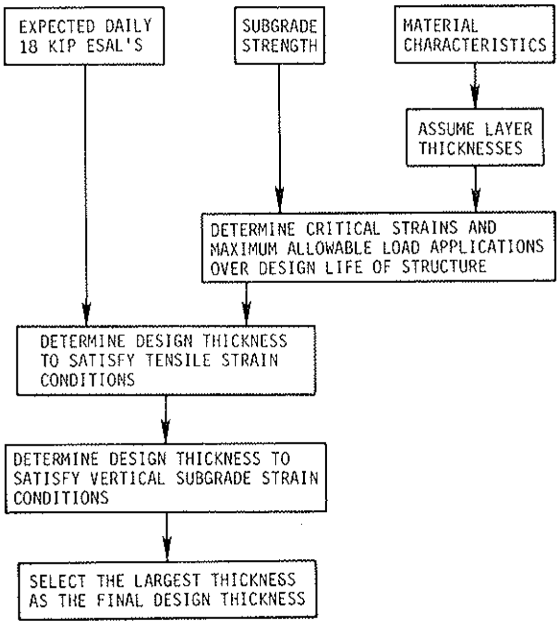

FIGURE 6 Flow diagram for the Chevron asphalt pavement design method.

AASHTO

The most widely used equivalent axle load factors are those developed from the original AASHO Road

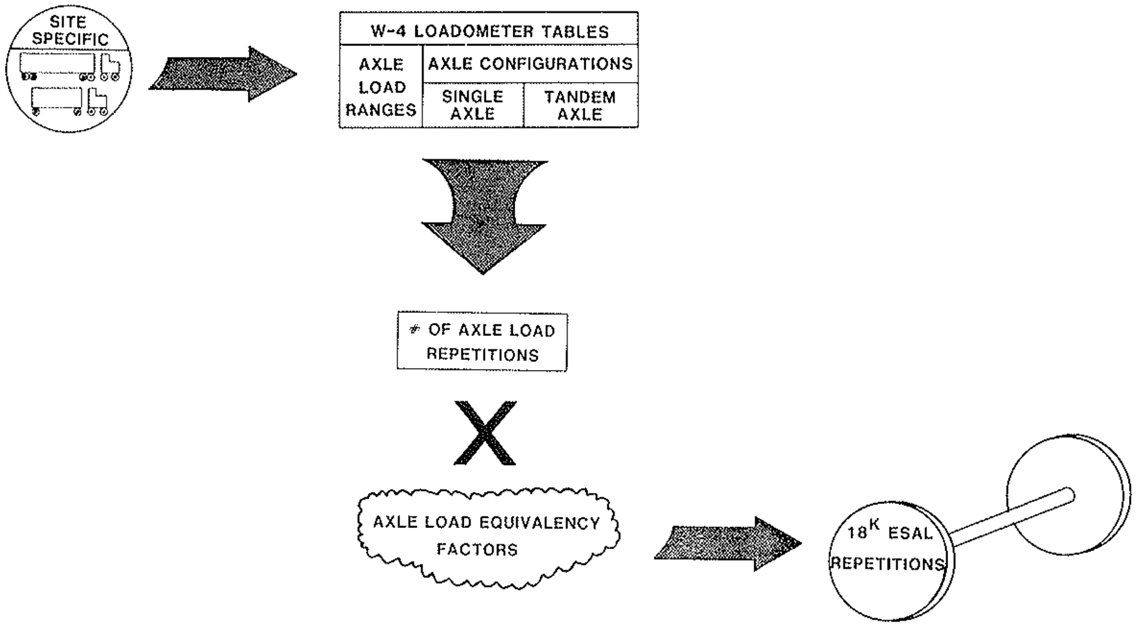

FIGURE 7 Reduction of traffic data to equivalent axle loadings.

TABLE 1 Contrast of Equivalent Axle Loads Calculated Using the AASHTO, Monismith, and Shell Equivalency Procedures for Single Axles for Hypothetical Pavement Problem in Which SN = 3.0, p = 2.5.

Axle Load		No. of Axles	Equivalency Factors			Equivalent 18-kip (80-kN) Axle Loads		
(kips)	(kN)		AASHTO *(2)*	Monismith *(6)*	Shell *(7)*	AASHTO	Monismith	Shell
2	8.9	500	0.0003	0.0002	0.0001	0.15	0.1	0.05
6	26.7	500	0.02	0.012	0.011	10	6	5.5
10	44.5	1,000	0.12	0.096	0.086	120	96	86
14	62.3	300	0.40	0.37	0.33	120	111	99
18	80.0	200	1.00	1.00	0.90	200	200	180
22	97.8	100	2.17	2.23	2.01	217	223	201
26	115.6	10	4.31	4.36	3.93	43.1	43.6	39.3
Total						710.25	679.7	610.85

TABLE 2 Contrast of Equivalent Axle Loads Calculated Using the AASHTO, Monismith, and Shell Equivalency Procedures for Tandem Axles for Hypothetical Pavement Problem in Which SN = 3.0, p = 2.5.

Axle Load											
Tandem		Single		No. of Axles		Equivalency Factors			Equivalent 18-kip (80-kN) Axle Loads		
(kips)	(kN)	(kips)	(kN)	Tandem	Single	AASHTO *(2)*	Monismith *(6)*[a]	Shell *(7)*[a]	AASHTO	Monismith	Shell
4	17.8	2	8.9	20	40	0.01	0.0002	0.0001	0.2	0.008	0.004
12	53.4	6	26.7	300	600	0.02	0.012	0.011	6	7.2	6.6
20	89.0	10	44.5	500	1,000	0.16	0.096	0.086	80	96	86
28	124.5	14	62.3	800	1,600	0.55	0.37	0.33	440	592	528
36	160.1	18	80.0	150	300	1.38	1.00	0.90	207	300	270
Total									733.2	995.208	890.604

[a] One tandem axle is considered to be two single axles.

Test pavement design procedure (2). In response to a 1982 study, 43 state transportation agencies stated that they used the AASHTO guide in determining wheel-axle load equivalencies (11,pp.1-4). This procedure computes the number of axle load repetitions to failure for the pavement being designed. The number of repetitions is a function of pavement rigidity, load characteristics, and terminal serviceability value. The load characteristics consist of the magnitude of the axle load and the axle configuration (single or tandem). The actual equivalency factor (F_j) is given as the ratio of the number of repetitions to failure for a standard 18-kip single axle load ($N_{f_{18}}$) to the number of repetitions to failure for the given axle load and configuration (N_{f_j}). This ratio has been defined as a regression equation that includes the variables of axle load (L_1), axle configuration (L_2), and pavement characteristics (G, β, a, b):

$$F_j = N_{f_{18}}/N_{f_j}$$

$$= [(L_1 + L_2)^a/(18 + 1)^a][10^{G/\beta}/(10^{G/\beta_j})L_2^b] \qquad (4)$$

Values of the equivalent axle load factor have been tabulated as computed functions of the structural number (flexible pavements), the pavement thickness (rigid pavements), the terminal serviceability (P_t), the axle load, and the axle configuration (2).

Asphalt Institute

The Asphalt Institute pavement design method for heavy wheel loads (5) incorporates traffic data as equivalent single wheel loads rather than as equivalent single axle loads. This method is typical of airport pavement design procedures on which the design methodology is based. The standard highway pavement design procedure set forth by the Asphalt Institute, however, uses the AASHTO equivalency factors.

Monismith

Monismith's procedure defines the load equivalency factor (EF_w) in terms of axle loads:

$$EF_w = (W/80)^4$$
$$= 2.44 \times 10^{-8} W^4 \qquad (5)$$

where

EF_w = axle load equivalency factor,
W = any particular axle load (kN), and
80 = standard axle load (kN).

The 80-kN standard axle load is roughly equivalent to the 18-kip standard axle load of the AASHTO design (6).

Shell

The Shell design procedure also stipulates the use of ESALs through an equation nearly identical to Monismith's:

$$n = 2.2 \times 10^{-8} L^4 \qquad (6)$$

where n is axle load equivalency factor and L is other axle load (kN). The standard axle consists of two dual 20-kN wheels with contact stresses of 600 kN per square meter and a loaded area radius of 105 mm. This relationship is based on the AASHTO equivalency factors (7).

Chevron

Traffic is reduced to 18-kip ESALs for the Chevron pavement design procedure. A particular formula for calculating the 18-kip ESAL is not given, thus allowing the designer to use his own judgment in choosing an equivalency definition.

Chua and Lytton

The procedure of Chua and Lytton does not include load equivalency factors. Individual traffic loads are directly incorporated and the resulting rut depths are calculated (9).

Recent Developments in Equivalency Factors

A significant problem arises when an attempt is made to use the AASHTO or related equivalency factors for situations that do not fall within the scope of the AASHTO experimental data. An example of this conflict is the evaluation of new or unique truck axle configurations. Extrapolation of the AASHTO equivalency factors for these new trucks is not adequate, and therefore new approaches are necessary.

A fundamental relationship for the equivalency factor was devised by Treybig (3). This relationship results in factors similar to the AASHTO factors for identical situations, but it also provides for the calculation of factors for axle loads and configurations not represented by the original AASHTO equivalency factors. The equation for the equivalency factors [$F(X_n)$] (3,p.36) is

$$F(X_n) = [\varepsilon_1(X_n)/\varepsilon(18_s)]^B$$
$$+ \sum_{i=1}^{n} \{[\varepsilon_{i+1}(X_n)] - [\varepsilon_{i-i+1}(X_n)]/\varepsilon(18_s)\}^B \qquad (7)$$

$$B = \log F(X_s)/\log [\varepsilon(X_s)/\varepsilon(18_s)] \qquad (8)$$

where

$F_i(x_n)$ = equivalency factor for axle configuration n of load x,
$\varepsilon(18_s)$ = maximum asphalt strain or subgrade vertical strain for the 18-kip ESAL,
$\varepsilon_1(X_n)$ = maximum asphalt strain or subgrade vertical strain under the leading axle or axle configuration of load x,
$\varepsilon_{i+1}(X_n)$ = maximum asphalt strain or subgrade vertical strain under axle i + 1 of axle configuration n of load x,
$\varepsilon_{i-i+1}(X_n)$ = maximum asphalt strain or subgrade vertical strain in the critical direction between axles i and i + 1 of axle configuration n of load x.
$\varepsilon(X_s)$ = maximum asphalt strain or subgrade vertical strain for an x-kip single axle load, and
$F(X_s)$ = AASHTO equivalency factor for an X-kip single axle load.

This equation should only be applied to pavements that are similar to those of the AASHO Road Test with respect to material properties and thicknesses. Also, this relationship is only applicable to flexible pavements; a similar relationship derived for rigid pavements did not correlate well with the AASHTO values.

The trend toward theoretically based equivalency factors was continued by Sharma et al. (4). Their method converts mixed traffic with single or tandem axles and dual tires or single tires of various widths to equivalent 18-kip dual-tire single axle load applications (Figure 8). Two separate sets of equivalency values were computed, one for flexible pavements and another for rigid pavements.

For flexible pavements the calculation of equivalent wheel load factors began with elastic layer theory to calculate maximum horizontal strains. Next, the number of axle load repetitions until failure was determined using fatigue analysis. The equivalent wheel load factors were then computed for single tires (widths = 10, 12, 14, 16, and 18 in.) on single axles to allow conversion to 18-kip dual-tire (width = 10 in.) single axle loads. Both the flexible and the rigid pavement equivalent wheel load factors were verified by field studies (4).

Rigid pavement procedure entailed the use of a finite element analysis, ILLI-SLAB, to calculate maximum flexural stresses. Warping stresses are then added to the flexural stresses; the combination is then used to calculate the number of axle repetitions to failure using fatigue analysis. Finally,

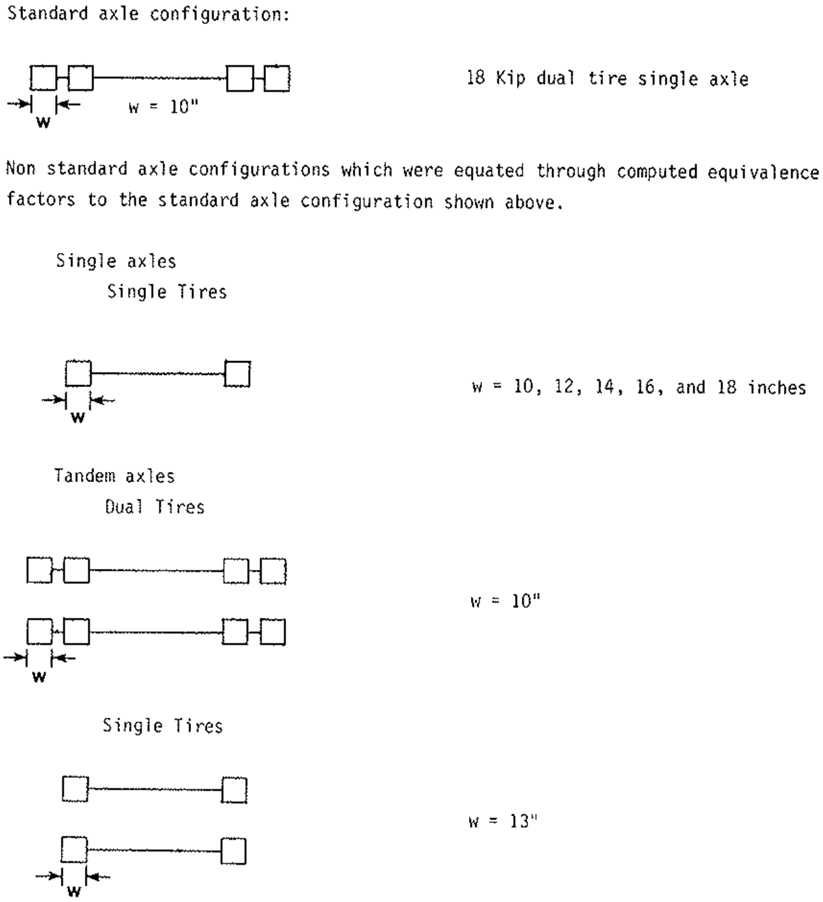

FIGURE 8 Axle configurations examined by Sharma, Hallin, and Mahoney *(4)*.

equivalent wheel load factors were developed for single tires (widths = 10, 12, 14, 16, and 18 in.) on single axles, dual tires (width = 10 in.) on tandem axles, and single tires (width = 13 in.) on tandem axles as conversion factors to 18-kip dual-tire (width = 10 in.) single axle loads (4).

PAVEMENT MANAGEMENT SYSTEMS

If the various design theories are correct in assuming shorter life expectancies and increased distress levels for pavements subjected to heavier, wider, and longer trucks, then the ability to monitor these pavements becomes essential. Pavement management systems (PMSs) are techniques or methodologies used to assess the condition of a current pavement network, predict the location of future distresses, and rank the scheduling of necessary maintenance in order of priority. Fiscal restraints and responsibilities support the implementation of a PMS to ensure the efficient use of money and materials.

Pavement management systems are necessarily tailored to each agency's needs and desires. The level of comprehensiveness varies greatly. Current systems range from those that are primarily visual and subjective to empirical models that estimate various pavement distresses and related serviceability. In general, the effects of truck traffic are included through fixed percentage increases in the number of 18-kip ESAL repetitions. Seasonal variations and subgrade condition and composition are also incorporated in most current PMS procedures. Several examples illustrate the implementation of a PMS.

Arvada, Colorado

The city of Arvada, Colorado, implemented a method of monitoring and evaluating the present condition of the pavement network in order to identify and recommend immediate and future corrective measures (12). A visual inspection of the network is made to note and rate various types of pavement distress. Ride quality is determined and the condition of structural appurtenances is also recorded. Individual deduct values are determined for each distress noted, and a pavement condition rating score (PRS) is calculated. A computerized decision tree is then used to obtain the optimum rehabilitation techniques and associated costs. Finally, a priority value is calculated as a function of cost, length of pavement, average daily traffic, PRS, and presence of industrial or commercial vehicles (trucks). No distinction is made with respect to type of trucks involved, axle loadings, or axle configurations.

Alberta, Canada

The PMS used by the province of Alberta, Canada, is an empirically based procedure that incorporates pavement performance prediction models to identify both current and future needs (13). Field measurements are first obtained. Then these measurements are used as input for several regression equations to determine three indices: a riding quality index (RQI) represents the roughness of the pavement; the structural ability of the pavement to withstand traffic is based on a structural adequacy index

(SAI); and severity and extent of surface distress are recorded as a visual condition index (VCI). The overall quality of the pavement is represented by the pavement quality index (PQI), which is a function of RQI, SAI, and VCI. Rehabilitation needs are then established for each index. The inclusion of truck traffic is accomplished in the calculation of SAI and is based on the number of 18-kip ESAL repetitions. Approximate axle load equivalency factors are therefore a necessary requirement.

Texas Flexible Pavement Damage Functions

Texas flexible pavement damage functions also rely on an estimate of 18-kip ESAL repetitions (10). The Texas method requires the input of the average daily traffic count, the percentage of trucks, the flexible base thickness, the subgrade Atterburg limits, the maximum Dynaflect deflections, and climatic data. The number of 18-kip ESAL repetitions is calculated and used as input to several pavement distress equations. Pavement distress equations have been developed to examine rutting, flushing, alligator cracking, raveling, and longitudinal cracking. A pavement score ranging from 0 to 100 is then obtained with a value of 35 defined as "failure." The distress types deemed most significant at the time of failure are identified. Appropriate rehabilitation strategies can then be recommended to remedy the condition.

TRUCK IMPACT STUDIES

Oil Field Traffic

The usefulness of the Texas pavement distress methodology was demonstrated in a study conducted for the Texas State Department of Highways and Public Transportation (14). This study illustrated the effects of oil field truck traffic on low-volume, surface-treated flexible pavements. A computer program was created that estimates the service life of thin surface-treated pavements serving both oil field traffic and original "intended-use" traffic. In addition to the Texas flexible pavement distress equations, the program also determines a pavement serviceability index based on the standard AASHTO 18-kip ESAL equivalency factors.

Double Bottoms

Impacts of the 1982 STAA permitting larger trucks are difficult to ascertain. This point is evident in a study by Tobin and Neveau (15) who investigated the effects of tandem trailers (double bottoms). The assumptions on which the study was based are critical in that the presence of double bottoms could either increase or decrease the number of axle loadings and correspondingly the amount of pavement deterioration. If the freight tonnage were to remain constant and be carried via double trailers rather than single trailers, then the number of axle loadings would be smaller because there would be fewer tractors. Shipping via doubles, however, is less costly per freight unit than shipping via singles. Therefore the allowance of doubles could result in greater freight tonnage and, hence, more trucks and more axle loadings.

The AASHTO 18-kip ESAL equivalency factors were used to model the truck axles and obtain pavement deterioration rates. Study results indicate that, in the short term (10-year span), the impact of tandem trailers appears to be negligible with respect to maintenance costs. For the long term (20-year span) no clear relationship could be identified between maintenance costs and pavement deterioration rates. The ambiguity lies in the various accompanying factors including percentage of trucks, type of maintenance, and maintenance scheduling.

Productivity Savings

Economic implications of the 1982 STAA for governing entities with respect to pavement management must also be viewed from the perspective of increased productivity. Although the STAA permitted larger trucks, it also provided for increased taxes to be levied on the trucking industry. Nevertheless, the U.S. Department of Transportation estimated a net productivity savings for the trucking industry of $3.24 billion. The American trucking industry, however, calculated a net productivity savings of $829 million to be realized from the time of passage of the bill until 1985 (16).

SUMMARY

The effects of heavier, wider, and longer trucks permitted by the 1982 STAA are not well established at this time. Various pavement management systems are, however, being used to monitor roadway systems and will provide insight into the contribution of traffic to pavement failure. Each system discussed in this paper relies primarily on conversion of the traffic data to 18-kip ESALs through AASHTO load equivalency factors.

Axle load equivalency is the fundamental concept through which mixed traffic is transformed for use in pavement design and pavement management. This traditional methodology is also being used to measure the effects of new truck sizes and axle configurations. Most widely used is the AASHTO conversion to 18-kip ESALs (11).

Extrapolation of the AASHTO 18-kip equivalency factors for the new axle configurations of larger trucks is not possible because of limitations of the empirical data on which the existing factors are based. Various attempts have been made by Treybig (3) and Sharma et al. (4) to establish sets of theoretically based equivalency factors that would be capable of modeling the heavier loads and various axle configurations permitted by the 1982 STAA.

Research is limited in the area of load equivalency factors. If the axle load equivalency concept continues to be applied in analysis, then additional efforts will be necessary to determine the proper values for implementation. Changes, such as those brought about by the 1982 STAA, require continued investigations to more closely identify, assess, and predict the impacts of longer, wider, and heavier trucks.

REFERENCES

1. R.L. Lytton. Pavement Performance and Monitoring in the U.S.A. Texas Transportation Institute, Texas A&M University, College Station, Tex., 1985.
2. E.J. Yoder and M.W. Witczak. Principles of Pavement Design. John Wiley and Sons, Inc., New York, 1975.
3. J. Treybig. Equivalency Factor Development for Multiple Axle Configurations. In Transportation Research Record 949, TRB, National Research Council, Washington, D.C., 1983, pp. 32-47.

4. J. Sharma, J. Hallin, and J.P. Mahoney. Evaluation of Present Legislation and Regulations on Tire Sizes, Configurations and Load Limits. University of Washington, Seattle, July 1983.
5. A Guide for the Design of Full-Depth Asphalt Pavements for Heavy Wheel Loads. Report MISC-75-5. The Asphalt Institute, College Park, Md., Sept. 1975.
6. C.L. Monismith. An Introduction to the Analytical Design of Asphalt Concrete Pavements. University of California, Berkeley (material adapted from notes prepared by S.F. Brown, University of Nottingham, England), undated.
7. A.I.M. Claessen, J.M. Edwards, P. Sommer, and P. Uge. Asphalt Pavement Design: the Shell Method. In Manual on Asphalt Pavements and Overlays for Road Traffic, Shell International Petroleum Company Ltd., London, England, 1978.
8. L.E. Santucci. Thickness Design Procedure for Asphalt and Emulsified Asphalt Mixes. Fourth International Conference on the Structural Design of Asphalt Pavements, University of Michigan, Ann Arbor, Aug. 1977.
9. K.M. Chua and R.L. Lytton. Load Rating of Light Pavement Structures. In Transportation Research Record 1043, TRB, National Research Council, Washington, D.C., 1985, pp. 89-102.
10. R.L. Lytton, T. Scullion, B.D. Garrett, and C.M. Michalak. Effects of Truck Weights on Pavement Deterioration. Final Report RF 4087-2. Texas Transportation Institute, Texas A&M University, College Station, Tex., Sept. 1981.
11. A.L. Skok, H.N. Doty, F.N. Finn, and M. Lyon. Traffic Factors Used in Flexible Pavement Design. Transportation Research Circular 240. TRB, National Research Council, Washington, D.C., April 1982.
12. R.F. Carmichael III, and J.B. O'Grady. Pavement Management--One City's Experience. In Transportation Research Record 938, TRB, National Research Council, Washington, D.C., 1983, pp. 36-43.
13. M.A. Karan, T.J. Christison, A. Cheetham, and G. Berdahl. Development and Implementation of Alberta's Pavement Information and Needs System. In Transportation Research Record 938, TRB, National Research Council, Washington, D.C., 1983, pp. 11-20.
14. J.M. Mason, T. Scullion, and B. Stampley. Estimating Service Life of Surface-Treated Pavements in Oil Field Areas. Research Report 299-2. Texas Transportation Institute, Texas A&M University, College Station, Tex., July 1983.
15. G. Tobin and A.J. Neveu. Impact of Double Trailers on Pavement Condition. Presented at 64th Annual Meeting of the Transportation Research Board, Washington, D.C., 1985.
16. Analysis of the Department of Transportation's Claim of the Benefits Accruing to the Trucking Industry from the Surface Transportation Assistance Act of 1982. American Trucking Associations, Inc., Alexandria, Va., July 1983.

TRB's Study of Twin-Trailer Trucks

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ABSTRACT

The Surface Transportation Assistance Act (STAA) of 1982 legalized the nationwide use of twin-trailer trucks on Interstate highways and other designated primary routes. In this paper will be reviewed what is known to date about the effect this legislation has had on the trucking industry--who is using these vehicles, where, and for what purposes. This information, coupled with earlier research findings concerning twins and other heavy trucks, will be used as the basis for a brief discussion of the likely effects of twins on the design, maintenance, and operations of highway facilities. Specific topics will include road geometry, pavements, bridges, and traffic capacity. Throughout, references will also be made to other new trucks legalized by the 1982 STAA--the 48-ft single-trailer truck and 102-in.-wide trucks.

Twin-trailer trucks--truck tractors pulling two trailing units with individual lengths of 27 to 28 ft--have been operating in the United States for more than 35 years, but their operation has been confined principally to the far West. In the Surface Transportation Assistance Act (STAA) of 1982, the Congress required states to permit the operation of twins, as well as longer semitrailer trucks (with trailer lengths of at least 48 ft) and wider semitrailers (up to 102 in.), on Interstates and primary routes designated by the Secretary of Transporta-

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