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TRAFFIC FACTORS USED IN FLEXIBLE PAVEMENT DESIGN

mode
1 highway transportation

subject area
24 pavement design and performance

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INTRODUCTION

The traffic effect on flexible pavements has been predicted and defined in various ways throughout the years. Originally the design of a given pavement was based on the thickness required to prevent a given load from completely failing the structure. For higher traffic volumes, the maximum design load was increased to account for the cumulative damage effect of increased applications of the lower normal loads. The equivalent load concept was defined in the 1940's in California using as a base a 5000 lb single wheel load; factors greater or less than 1.0 were used for wheel loads greater or less than 5000 lbs respectively. The development of traffic load factors on pavements is covered in a number of textbooks such as Yoder and Witczak (1).

The AASHO Road Test was the first project where the relative effect of traffic could be evaluated based on performance of test sections under multiple application of identical vehicle loads. The relative effect, or equivalency, is based on the number of applications a given pavement thickness design can withstand before its condition is reduced to a level such that maintenance or rehabilitation is required. The gradual reduction in service level represents a load related fatigue-type deterioration. The relative effect of different axle loads depends also on the environment, and this must be considered in design procedures. The equivalency factors from the AASHO Road Test were presented in an interim guide published in 1961 and revised in 1972 (2).

In order to use the equivalency factors it is necessary to predict the number of various axle loads that will be applied to a pavement during its life. This requires not only a prediction of total traffic but also the random mixture of vehicles with different axle loads and numbers of axles that constitute normal highway traffic. Planning and programming procedures use traffic sampling data to predict total volume, vehicle type and lane distribution over the design period for a road facility. It is not possible or necessary to make exact predictions, but variations must be considered in the volume and nature of the traffic.

The Transportation Research Board Committee A2B02 on Flexible Pavement Design has an interest in the methods used by transportation agencies to evaluate the traffic loadings which their pavements are called upon to support. Of particular interest are the means employed by each agency to assess the impact of increased load limits and changes in vehicle configuration on the life of existing pavements and what means are employed to monitor and compare traffic loadings to the forecasts used in original pavement designs. A subcommittee of Committee A2B02 was appointed to develop information on the subject. The data presented in this circular were collected using the appended questionnaire which was sent to all state transportation agencies, the District of Columbia and Puerto Rico. The responses will help determine if research is needed to study the relative traffic effect and if there is enough information available to evaluate different vehicle configurations which might be proposed.

QUESTIONNAIRE SUMMARY AND DISCUSSION

Forty-seven of the fifty-two agencies responded to the questionnaire (see APPENDIX). One agency did not provide detailed information but indicated that flexible pavements were designed based on experience. The answers are summarized below using the same order in which the data were solicited. Short summaries are given for special methods or procedures.

Question Number

1. Pavement design method (AASHTO, Hveem, CBR, other).

AASHTO	33
Hveem stabilometer	6
CBR	1
Other	7

(a) Kansas Triaxial

(b) Kentucky Method
(c) Missouri State Highway Department Method based on 2 axle equivalents (2AE) and Soil Index
(d) Table of Standard Designs or Method based on statistical analysis of New York pavement performance
(e) Oklahoma Subgrade Index-Equivalent Base Thickness
(f) Texas Flexible Pavement Design System
(g) No formal method

2. How is the traffic factor expressed? (Eq. 18K, EAL, EWL, other)

Equivalent 18 Kip Single Axle (E18KSAL)	35
Equivalent Axle Load (EAL)	7
Equivalent Wheel Load (EWL)	5
Other	3

(a) 20-year Traffic Index
(b) 2AE
(c) Design Heavy Vehicle (DHV) and E18KSAL

All of the parameters used for pavement design are essentially equivalent load methods. That is, in some way all axle load distributions are converted to an equivalent number of some base load. The EAL, EWL, Traffic Index, 2AE and E18KSAL are essentially the same concept. The DHV is a vehicle load which cannot be exceeded even for a few applications. It defines the heaviest vehicle for a given design in addition to defining the fatigue effect using the equivalent load concept.

3. How are wheel-axle load equivalencies determined? (AASHTO Guide, other data, explain)

AASHTO Guide	43
Other	2

(a) Kentucky 1981 damage factors are calculated by the general equation:

$$10^{[a + b \log P + c(\log P)^2]}$$

where P = load, kips

For Single Front Axles:
a = -3.54011
b = 2.72886
c = 0.28913

For Single Rear Axles:
a = -3.43950
b = 0.42375
c = 1.84666

For Tandem Axles:
a = -2.97948
b = -1.26514
c = 2.00799

(b) Oregon Equivalent 5000 lb wheel loads (EWL)

$$\left[\left(\frac{W_2}{5}\right)\right]^{4.2} \quad \text{Single Axle}$$

$$\left[\left(\frac{W_2}{5}\right) \times 1.1\right]^{4.2} \quad \text{Tandem Axle}$$

The axle loads defined using the factors given in this section are mostly for dual wheel loads. The Kentucky method includes an equation for axles with single tires rather than duals. A recent study in Alberta, Canada by J. F. Christianson and B. P. Shields (3) also has determined equivalencies for these axles. Table 1 is a summary of a comparison between equivalencies determined using AASHTO factors, the Kentucky formula and equivalencies determined from the Alberta study. The factors relate the effect of the indicated axle loads to an 18,000 lb single axle load.

Table 1

18,000 Single Axle Load Equivalency Factors for Axles with Single Tires Compared to AASHTO Equivalencies

AXLE LOAD LB	LOAD EQUIVALENCY FACTORS		
	AASHTO*	KENTUCKY**	CHRISTIANSON & SHIELDS
2,000	0.00018	0.0020	<0.004
5,000	0.0050	0.0323	0.06
10,000	0.088	0.3005	0.6

*AASHTO
P = 2.5
SN = 5
**KENTUCKY

$$10^{[-3.54011 + 2.72886 \log P + 0.28913(\log P)^2]}$$

4. What is the source of your information on truck weights? (W-4 tables, loadometer surveys, etc.)

W-4 Tables	29
Loadometer Surveys	15
Other	1

The W-4 tables are developed from loadometer surveys. Therefore, all agencies use some type of field determined load data to evaluate the load distribution of vehicles in their system. Some reservations were expressed in Question 7 as to how representative the distribution of axle loads was at fixed weight stations compared to other locations. With permanent weigh stations and voluntary weighings, it is doubtful if a true picture of actual loads using a given pavement can be obtained. Some type of weigh-in-motion system which can be moved from section to section would be best for getting a more representative distribution of axle loads.

5. How many field locations are used in determining truck weight data:

No. Locations	No. Agencies
5	1
6	1
8	4
10	2
11	1
12	4
13	3
14	4
15	3
16	2
17	3
18	1
19	1
20	4

No. Locations	No. Agencies
21	2
23	1
26	1
27	1
28	1
64	1
As needed	1

6. When are truck weights determined?

(a) Season

Summer	35
Winter	1
Spring	2

(b) Time of Day

	Number
6 AM - 10 PM	9
8 AM - 4 PM	11
6 AM - 8 PM	2
7 AM - 3 PM	2
7 AM - 6 PM	2
6 AM - 2 PM	1
24 hrs.	2
7 AM - 11 PM	1
11 PM - 7 AM	1

(c) Length of Count

	Number
24 hours	17
8 hours	9
16 hours	4
7 hours	1
12 hours	1
11 hours	1
14 hours	1
3 consecutive 24 hours	1

7. Do your evaluation procedures adequately predict truck weights and equivalencies?

(a) Yes	19
No	26

(b) List of reasons traffic evaluation procedures don't adequately predict truck weights and applied wheel or axle loads on all systems.

(1) Load meter surveys not accurate (i.e. "CB" radio allows truckers to avoid portable scales).
(2) Data lacking on roads of low function class (i.e. minor collectors, local roads, etc.).
(3) Insufficient frequency and dispersion of measuring points.
(4) Field surveys are only made on selected systems.
(5) No definitive data for secondary and local road systems have been collected in Illinois.
(6) Permanent weigh sites are predominantly on interstates and heavily travelled primary routes.
(7) Depends on limits set by law.
(8) Predicts number of 2AE's only (Missouri).
(9) It is impractical for NJ DOT to set up stations on a state highway in an urban area because of lack of space.
(10) Percent of trucks is based on traffic counts which do not agree with truck weight studies.
(11) Because of the nature of the truck weight study.
(12) Weighings are voluntary. Don't believe heavy or overloaded trucks participate (Ohio).
(13) Continuous class data not available to show 24 hr. daily and monthly variations (R.I.).
(14) Sample of weighing stations is designed only to estimate system-wide averages.
(15) Load factors used are based on W-4 which represents all mainline rural state truck highways, including interstate.

(c) Do procedures adequately account for variations occasioned by seasonal hauling or industrial hauling patterns?

Yes	21
No	15
Somewhat	7

8. Truck Data Used.

State or system-wide	24
Job-by-job	21
Both	1

9. Method of classifying truck count.

Heavy and light	6
Number of axles	19
Truck type	25
Single and Multiple units	2
Number and percent function of AADT	1

10. In determining wheel or axle-load equivalencies, do you consider:

	Yes	No
(a) tire width	4	42
(b) axle spacing	29	17
(c) wheel spacing	2	44
(d) pavement structural properties	25	21
(e) tire pressure	3	43
(f) W-4 Tables from FHWA	2	--

11. Do you distinguish between single wheel axle and dual wheel single axle in establishing equivalencies?

Yes	15
No	31

12. Is your equivalency based on a single axle or tandem axle?

Single	25
Tandem	3
Both	18

13. Have you established a ratio of equivalency between single and tandem axle loads?

Yes	27
No	17
No answer	2

14. If legal axle limits are raised could pavement design system recognize this effect?

(a) On new designs

Yes	36

No	9
No answer	1

(b) On serviceability of existing pavements (reduced life)

Yes	29
No	15

15. Do your truck weight census data indicate a significant or noticeable increase in truck weights since the change in AASHTO legal limits to 20 kip single and 34 kip tandem?

Yes	34
No	12

16. For Question 16, three truck types and set of axle loads were presented (see questionnaire). The agencies were asked to give their calculation of the total effects of those specific vehicles in terms of equivalent 18,000 lb single axle loads. In other words, they were asked to determine the effect on the pavement in terms of equivalent loads each time that truck with the axle loads shown went over the section. Three levels of loading were used for each truck type. The levels were not considered equivalent.

Table 2 is a list of means and standard deviations based on the calculations of truck effects. The means and standard deviations were calculated using 28 values. Two of the sets were not used in the calculations because the factors in one case were quite low and in another were quite high for the heavier loads. Another set of values was not used because they were given in terms of annual EWL and it wasn't possible to convert these to equivalent 18,000 lb single axle loads.

Table 2

Summary of Equivalent Load Effect for Single Unit, Semi-Trailer and Double Bottom Trucks
28 Values Used for Mean and Standard Deviations

Loading	Mean	Standard Deviation
Single Unit A	1.02	0.14
Single Unit B	1.58	0.14
Single Unit C	4.78	1.05
Semi-Trailer A	2.04	0.62
Semi-Trailer B	3.02	0.78
Semi-Trailer C	6.55	2.44
Double Bottom A	4.05	0.36
Double Bottom B	6.53	0.66
Double Bottom C	20.42	5.18

So that the relative effect of the different types of trucks and axle weights can be determined, none of the values was used for an agency that had even one or two factors missing.

17. Referring to Question 16

(a) Which factors, tire size, inflation pressure, etc., did you not consider in calculations?

Both tire size and inflation	14
None considered	15
Tire size only	1
Inflation pressure only	0
All considered	9
Tire size, inflation and spacing	1
Axle spacing	1
Axle spacing only used	1

(b) Are there other pertinent factors that should be considered?

- Regional factor set at 2.0.
- Structural number exceeded by 0.3 to accommodate grade lines.
- Use structural number of 5.0 and terminal serviceability index of 2.50.
- Speed.
- Fatigue curve.
- National policy related to energy conservation in the post 1980 period.
- Terminal serviceability level.
- Type of pavement and serviceability index.
- Tandem axle arrangement is assumed to distribute load equally; if actual suspension system does not distribute load equally, damage must be calculated differently.
- Pavement structural properties.
- Other axle configurations such as tri-axle and a single bogie with single and tandem axles.
- Proper evaluation of steering axles; pavement type variations should include surface treated flexible bases as well as AC vs. PCC pavements.
- Speed and grade, concentration of trucks in one lane, unbalanced loads.

CONCLUSIONS

The responses to the questionnaires on the use of traffic data for the design of flexible pavements shows that there is no "standard" method for evaluating traffic. Agencies have almost all adopted the equivalent load concept. About 80% have adopted the equivalency values from the AASHO Road Test. There is a wide variety of methods used for accumulating the data necessary to use the equivalent or standard axle load procedure. This requires that the total traffic, distribution of vehicle types and distribution of axle weights by vehicle type be predicted over a design period. The weakest link in this system is the prediction of vehicle weight distribution. Permanent weigh stations cannot be expected to yield representative data for a whole system. With communications available now it is an easy matter to avoid these locations if a truck is known to be overloaded. Weigh-in-motion systems offer the most promising method of improving this information. The computer is also making the analysis of traffic information an easier task.

Each agency should try to improve techniques for predicting the load effect on pavements. The cost of improved predictions should be weighed against the cost of either overdesigning or underdesigning due to inaccurate measurements.

REFERENCES

1. E. J. Yoder and M. W. Witczak. Principles of Pavement Design, 2nd Edition. John Wiley & Sons, Inc., 1975.
2. AASHTO Interim Guide for Design of Pavement Structures, 1972. American Association of State Highway and Transportation Officials, Washington, D.C., 1972.
3. J. F. Christianson and B. P. Shields. A Field Investigation of Load Equivalency Factors for Various Wheel and Axle Configurations. CTAA, November 1978.

APPENDIX

TRANSPORTATION RESEARCH BOARD

Committee A2B02 - Flexible Pavement Design

QUESTIONNAIRE

Traffic Factors Used in Flexible Pavement Design

Please Return To:

Dr. Eugene L. Skok, Jr.
Department of Civil Engineering
155 Experimental Engineering Building
University of Minnesota
Minneapolis, Minnesota 55455

Identification:

Agency: ______________________________

Department: ______________________________

Prepared by: ______________________________

Title: ______________________________

Date: ______________________________

Telephone No.: ______________________________

If you desire that your replies to this questionnaire be held in confidence, please check here ☐

INTRODUCTION

In response to concerns expressed by some transportation agencies over effects of increased load limits, Transportation Research Board Committee A2B02 on Flexible Pavement Design has prepared a questionnaire covering the items used in determining the traffic factor for pavement design equations.

The questionnaire is designed to examine the procedures used by transportation agencies' design people to evaluate the traffic loadings which their pavements are called upon to support. Of particular interest are the means employed by each agency to assess the impact of increased loadings on the life of existing pavements, and what means are employed to monitor and compare traffic loadings to forecasts used in original pavement designs.

The information from completed questionnaires will provide researchers and administrators with a current picture of just how, and to what extent, traffic data are used in agency design.

Please return the completed questionnaire to Dr. Skok at the address shown above by May 31, 1978.

1. Pavement design method (AASHTO, Hveem, CBR, other) ______________________________

2. How is the traffic factor expressed? (Eq. 18K, EAL, EWL, other) ______________

3. How are axle or wheel-load equivalencies determined? (AASHTO Guide, other data, explain) ______________________________

4. What is the source of your information on truck weights? (W-4 tables, loadometer surveys, etc.) ______________________________

5. How many field locations are used in obtaining truck weight data? __________

6. When are truck weights determined?

(a) Season ____________ (c) Length of count _______
(b) Time of day ________ (d) Other ____________

7. (a) In your opinion, do your traffic evaluation procedures accurately predict truck weights and applied wheel or axle loads on all systems?

(b) If not, why? ______________________________

(c) How about variations occasioned by seasonal hauling or industrial hauling patterns? ________________________

8. In pavement design do you use state-wide or system-wide "average" truck data, or job-by-job truck data? ________________________

9. How do you classify the truck count? (heavy and light, number of axles, truck type, etc.) ________________________

10. In determining wheel or axle-load equivalencies do you consider:

(a) tire width _______ (d) pavement structural properties ____
(b) axle spacing _______ (e) tire pressure __________
(c) wheel spacing _______ (f) other factors (name) ________

11. Do you distinguish between a single-wheel single axle and a dual-wheel single axle in establishing equivalencies? ____________________

12. Is your equivalency based on a single axle or a tandem axle? __________

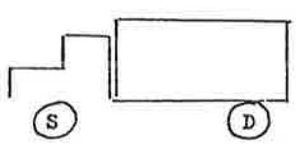
13. Have you established a ratio of equivalency between single- and tandem-axle loads? ____________________________

14. If legal limits are raised, is your pavement design system capable of recognizing effect of increased truck weights:

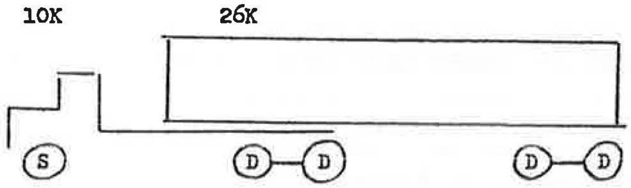
(a) on new designs __________
(b) on serviceability of existing pavements (reduced life) __________

15. Do your truck weight census data indicate a significant or noticeable increase in truck weights since the change in AASHTO legal limits to 20 KIP single and 34 KIP tandem? ________________________

16. With your design procedures can you calculate a vehicle load equivalency (in terms of total 18K equivalent axle loads) given tire size, tire pressure, wheel load, wheel and axle spacing? If so, please calculate the vehicle load equivalency for the following vehicles:



	S	D		Total Equivalencies
A.	6K	18K	=	________
B.	8K	20K	=	________
C.	10K	26K	=	________



	S	D–D	D–D		Total Equivalencies
A.	10K	32K	32K	=	________
B.	15K	34K	34K	=	________
C.	20K	40K	40K	=	________

	(S)	(D)	(D)	(D)	(D)		Total Equivalencies
A.	10K	18K	18K	18K	18K	=	________
B.	15K	20K	20K	20K	20K	=	________
C.	20K	26K	26K	26K	26K	=	________

(S) = single wheel, single axle
(D) = dual wheel, single axle
(D)—(D) = dual wheel, tandem axle

Assume: 80 psi inflation pressure
11 x 24.5 tires
4-ft tandem axle spacing
10-ft minimum single axle spacing

17. Referring to Question 16

(a) Which of the above factors, tire size, inflation pressure, etc., did you not consider in your calculations? ____________________

____

(b) Are there other pertinent factors you feel should be considered? ____ What are they? ____________________

____

18. Any comments on the general subject of truck loadings as related to pavement design and pavement performance:

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