APPENDIX C

CATEGORIZATION OF TRAFFIC LOADS

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INTRODUCTION

Traffic data is a key element for the design and analysis of hot mix asphalt overlay structure as well as new pavement construction. Also, the traffic loading is one of main factors to cause bending and shearing load stress of asphalt overlay on which reflection cracking is propagated. For compatibility with the Mechanistic-Empirical Pavement Design Guide (MEPDG), the standard traffic option is to specify the actual load distribution (spectra) for each axle types (single, tandem, tridem, or quadrem axle) for each vehicle (truck) class or number of tire (single or dual).

The daily traffic distribution data is used to analyze bending or shearing reflection crack propagation in asphalt overlay section. The distribution should be determined based on the traffic data collected at the field over the years. However, it is found that some sections do not have enough field data to determine their traffic characteristics, while some have complete historical traffic data. In order to consider the level of collected traffic data, the hierarchical approach was adopted in MEPDG and also used in this study. The three steps of level were defined based on the availabilities of collected traffic data and Weigh-In-Motion (WIM) data which is used to determine the normalized axle load distribution for each axle and vehicle types (12):

- Level 1: Very good knowledge of past and future traffic characteristics and site/segment specific WIM data
- Level 2: Modest knowledge of past and future traffic characteristics and regional default summaries WIM data
- Level 3: Poor knowledge of past and future traffic characteristics and national default summaries WIM data or only Average Annual Daily Truck Traffic (AADTT) available

CATEGORIZATION OF TRAFFIC LOADS

In order to analyze traffic load effects for reflection cracking, annual number of axle loads for each vehicle class and axle type would be entered in analysis process. The number of axle loads can be determined using the traffic load categorized based on the FHWA vehicle class, the axle type, and the number of tires.

Classification of Vehicles

FHWA defines vehicles into 13 classes depending on whether they carry passenger or commodities. Non-passenger vehicle which are from class 4 to class 13 are divided by the number of axles and the trailer units (15). While bus (vehicle class 4) is passenger vehicle, the term truck traffic is assumed to include both trucks and buses since the proportion of buses in the traffic flow is relatively small (16). Table C-1 presents the FHWA vehicle classification.

It is noted that since the light axle load groups, such as vehicle classes 1 to 3, do not have significant effects regarding load related distresses, the traffic analysis in this study took account of heavier load groups in which the vehicle classes 4 to 13 are included.

Axle Load Distribution Factor

The axle load distribution is defined as the classification of traffic loading in terms of the number of load application by each axle type (single, tandem, tridem, or quadrem) within a given range of axle load. The axle load distribution factor is the percentage of the total axle application in each load interval by an axle type for a specific vehicle class (classes 4 to 13) (14; 17). The load intervals for each axle types are represented in Table C-2.

The determination of the axle load distribution requires WIM data which is the number of axles measured within each axle load range by axle types of each vehicle class. In the LTPP guideline, it is noted that the vehicle axle weights should be collected using WIM sensor by vehicle classes, type of axle, and axle load intervals. Using measured WIM data, the distribution is calculated by average the number of axles measured within each load interval of an axle type for a vehicle class divided by the total number of axles for all load intervals for a given vehicle class. The normalized axle load distribution factors should be total 100 for each axle type within each truck class. Table C-3 presents an example of FHWA W-4 Truck Weight Tables in which WIM data are typically reported for vehicle classes 4, 5, 6, and 7of LTPP test section 180901 in 2004. Also, Figure C-1 shows the annual normalized single axle load distribution calculated using the data in Table C-3.

Table C-1. FHWA vehicle classification.

Vehicle Class	Schema	Description
4		Buses
5		Two-axle, single-unit trucks
6		Three-axle single-unit trucks
7		Four- or more than four-axle single-unit trucks
8		Four- or less than four-axle single trailer trucks
9		Five-axle single trailer trucks
10		Six- or more than six-axle single trailer trucks
11		Five- or less than five-axle multi-trailer trucks
12		Six-axle multi-trailer trucks
13	–	Seven- or more than seven-axle multi-trailer trucks

Table C-2. Load intervals for each axle type.

Axle Type	Axle Load Interval
Single Axles	3,000 ~ 40,000 lb. at 1,000 lb. intervals
Tandem Axles	6,000 ~ 80,000 lb. at 2,000 lb. intervals
Tridem Axles	12,000 ~ 102,000 lb. at 3,000 lb. intervals
Quadrem Axles	

Table C-3. Number of single axle loads for vehicle class 4 to 7 (LTPP section 180901 in 2004).

Axle Load (lb.)	Vehicle Class			
	4	5	6	7
3,000	0	53,818	183	11
4,000	10	54,606	558	52
5,000	42	39,113	993	139
6,000	175	20,289	1,099	168
7,000	988	24,555	2,426	252
8,000	10,687	22,491	5,617	298
9,000	9,713	13,719	8,154	365
10,000	10,156	12,839	12,423	879
11,000	6,011	7,127	8,945	1,516
12,000	5,875	6,413	7,725	2,913
13,000	3,409	3,511	3,257	2,464
14,000	2,947	3,128	2,289	2,710
15,000	1,640	1,756	975	1,740
16,000	1,239	1,513	725	1,419
17,000	679	834	285	664
18,000	446	800	235	423
19,000	212	424	104	159
20,000	181	360	73	111
21,000	106	261	44	70
22,000	51	131	22	46
23,000	41	135	6	26
24,000	21	85	4	9
25,000	24	90	3	12
26,000	11	43	1	7
27,000	4	33	1	2
28,000	1	12	3	1
29,000	4	25	0	1

Axle Load (lb.)	Vehicle Class			
	4	5	6	7
30,000	3	13	0	0
31,000	1	16	2	0
32,000	2	8	0	0
33,000	0	5	0	0
34,000	0	2	1	0
35,000	0	0	0	0
36,000	0	0	0	0
37,000	0	2	0	0
38,000	0	0	0	0
39,000	0	0	0	0
40,000	0	0	0	0
Total	54,679	268,157	56,153	16,457

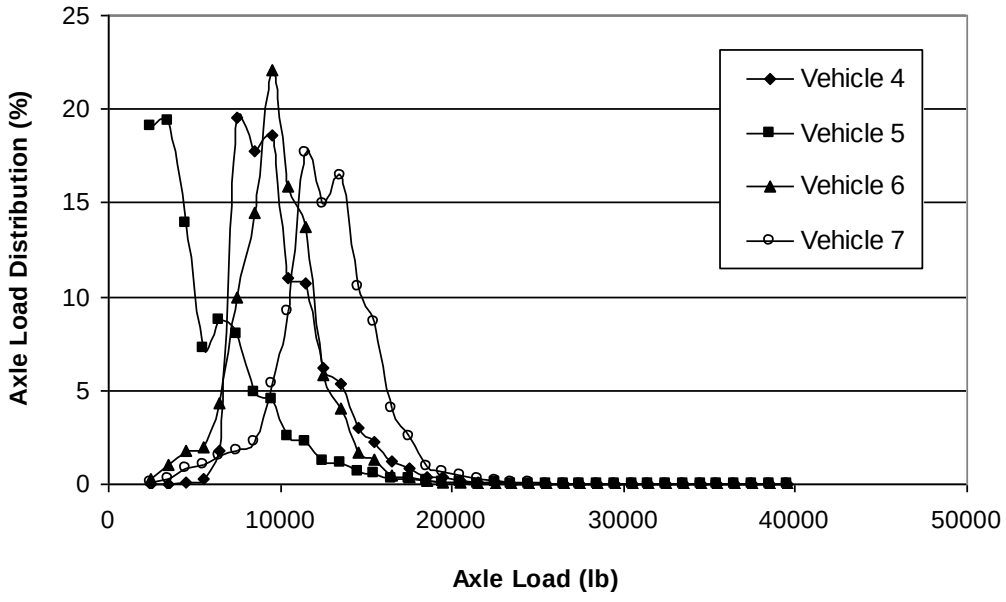

Figure C-1. Annual normalized single axle load distribution for vehicle class 4 to 7 (LTPP section 180901 in 2004).

It is observed that all axles of vehicle classes 4 and 5 and single axle of class 6 and 7 vehicles have single tires while the others have dual tires. Thus, the matrix of vehicle class and axle types can be categorized according to the number of tires. When the steering and non-steering axles are put together in single axle type, the matrix can be characterized into eight categories based on the vehicle class, the axle type, and the number of tires. The total number of axle loads for each category is used to further determine the axle load distribution factor for the analysis of the traffic load effect on reflection cracking. Figure C-2 shows the categorization of traffic load. The categories 1, 3, 5, and 7 have single tires and the categories 2, 4, 6, and 8 have dual tires.

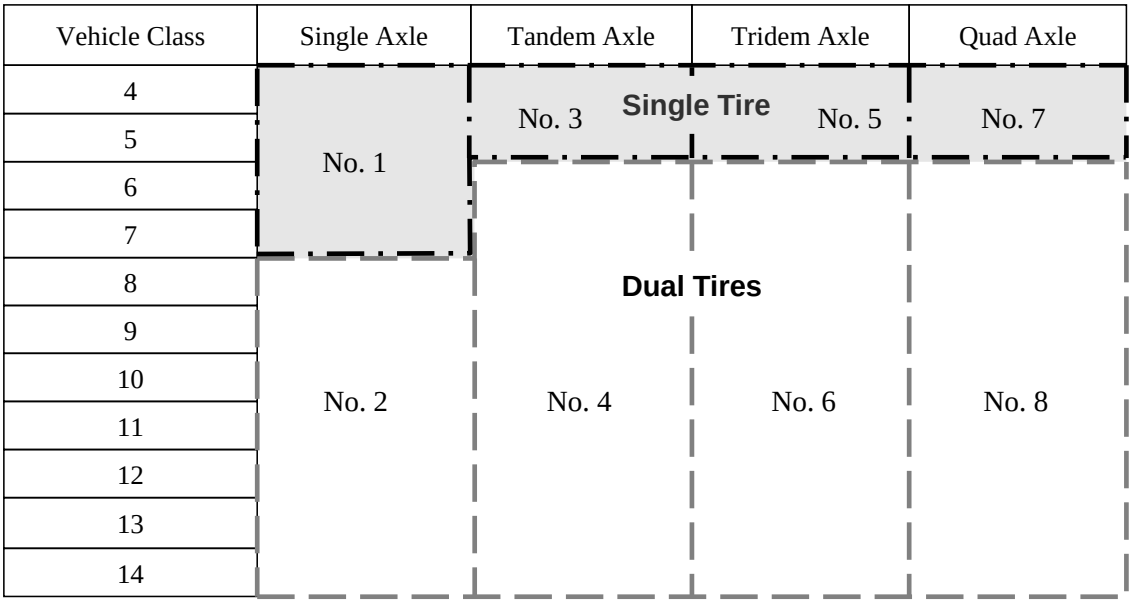

Figure C-2. Categories of traffic load.

Estimation of Annual Number of Axle Loads for Each Category with AADTT

The axle load distribution for each category should be calculated based on the total number of axle loads collected using WIM for each axle type within each vehicle class. However, depending on the level of data collection, some agencies might not have available WIM data to be used for evaluating reflection cracking on asphalt overlay. In order to facilitate the use of the traffic load categorization for such agencies or Level 3 data input, Annual Average

Daily Truck Traffic (AADTT) was adopted to convert it to the number of axle load for each category.

AADTT is the annualized averaged 24-hour volume of truck traffic passing a given section of highway. The truck traffic in AADTT consists of heavy vehicles from class 4 to 13 in FHWA vehicle classification (16). AADTT is determined based on traffic counts during a given time period which is whole days greater than a day but less than a year and can be calculated simply as follows (47):

$$AADTT = \frac{\text{Number of truck traffic for a given time}}{\text{Number of days for a given time}} \quad \text{(C-1)}$$

To convert AADTT into the annual number of axle loads for each vehicle and axle type, two truck-traffic adjustment factors are required: normalized vehicle class distribution and number of axles per truck.

Normalized Vehicle Class Distribution

The vehicle (truck) class distribution is the percentage of each vehicle class within the AADTT for the base year, and the sum of normalized distribution factors of all vehicle classes must be 100 (NCHRP 2004). The distribution is typically determined using data collected from vehicle classification counting programs such as WIM, AVC, or vehicle counts. Depending on inputs at different levels, the data can be obtained from a specific site, region/statewide, or national WIM, AVC, or vehicle counts. In this study, default vehicle class distribution factor is provided, which is determined using whole LTPP traffic data, as part of the developed software. The default value was obtained from the principal arterials in the roadway function class and the major multi-trailer truck route in Truck Traffic Classification (TTC) as shown in Table C-5 (14).

The annual number of trucks for each vehicle class within a base year can be calculated as follows;

$$ANT_k = AADTT \times 365 \text{ (day)} \times NTP_k \quad \text{(C-2)}$$

where

k = a specific vehicle class (class 4 to 13)

ANT_k = annual number of trucks for a vehicle class, k

NTP_k = normalized vehicle class distribution percentage for a truck class, k

In calculating the number of trucks for each vehicle, the normalized truck class distribution factors are assumed to be constant from year to year or the time of day.

Number of Axle Types per Vehicle

The number of axle types per vehicle is the average number of individual axles for each vehicle class for axle type (single, tandem, tridem, and quadrem). This number of axles is different from the number of axles for each vehicle as shown in Figure C-4. The latter values in Table C-4 is typical number of axles for each vehicle based on each vehicle schema, while the former is the calculated values using WIM data measured over time. The number of axle types per truck class can be determined by dividing the total number of a specific axle type measured for a truck class by the total number of trucks in that class. Table C-6 presents default values of the number of axle type per truck class which is estimated based on LTPP traffic data (14).

Using the number of axles for each vehicle and the total number of trucks for each vehicle class (ANT_k) calculated at previous step, the number of axle load for each axle type and vehicle class within a year can be calculated as follows:

$$NA_{ka} = ANT_k \times NAT_{ka} \quad \text{(C-3)}$$

where

a = a specific axle type (single, tandem, tridem, or quad)

NA_{ka} = annual number of axle loads for a axle type under a vehicle class

NAT_{ka} = average number of axles by axle type for each truck class

For example, when AADTT of an asphalt overlay section is 1500, ANT_k and NA_{ka} could be calculated, using the default values in Table C-5 and Table C-6, as shown in Table C-7.

Table C-4. Number of axles for each vehicle class.

Vehicle Class	Number of Axles			
	Single	Tandem	Tridem	Quadrem
4	1	1		
5	2 (1)*			
6	1	1		
7	1		1	
8	3 (2)			
9	1	2		
10	1	1	1	
11	5 (4)			
12	4 (3)	1		
13	3 (2)	2		

* ( ) is the number of non-steering single axle

Table C-5. Normalized vehicle class distribution factor.

Vehicle Class	Distribution Factor (%)
4	1.8
5	24.6
6	7.6
7	0.5
8	5.0
9	31.3
10	9.8
11	0.8
12	3.3
13	15.3

Table C-6. Average number of axles for each vehicle.

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quadrem Axle
4	1.62	0.39	0.00	0.00
5	2.00	0.00	0.00	0.00
6	1.02	0.99	0.00	0.00
7	1.00	0.26	0.83	0.00
8	2.38	0.67	0.00	0.00
9	1.13	1.93	0.00	0.00
10	1.19	1.09	0.89	0.00
11	4.29	0.26	0.06	0.00
12	3.52	1.14	0.06	0.00
13	2.15	2.13	0.35	0.00

From the result of Table C-7, the axle load for each category of the section having 1,500 of AADTT within a year can be determined as follows:

- Category 1: 15,965 + 269,370 + 42,442 + 2,738 = 330,515
- Category 2: 65,153 + 193,645 + 63,849 + 18,790 + 63,598 + 180,100 = 585,135
- Category 3: 3,843
- Category 4: 41,194 + 712 + 18,341 + 330,739 + 58,484 + 1,139 + 20,597 + 178,425 = 649,631
- Category 5: 0
- Category 6: 2,272 + 47,753 + 263+ 1,084 + 29,319 = 60,691
- Category 7: 0
- Category 8: 0

Table C-7. Results of number of axle loads for a section with AADTT = 1,500.

Vehicle Class (k)	No. of Vehicles (ANT_k)	Number of Axle Loads (NA_{ka})			
		Single Axle	Tandem Axle	Tridem Axle	Quadrem Axle
4	9,855	15,965	3,843	0	0
5	134,685	269,370	0	0	0
6	41,610	42,442	41,194	0	0
7	2,738	2,738	712	2,272	0
8	27,375	65,153	18,341	0	0
9	171,368	193,645	330,739	0	0
10	53,655	63,849	58,484	47,753	0
11	4,380	18,790	1,139	263	0
12	18,068	63,598	20,597	1,084	0
13	83,768	180,100	178,425	29,319	0

The results calculated using AADTT should be used for the section where WIM data is not available since the number of axle loads calculated from WIM data provides more accurate data than that estimated from AADTT does.