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Creation of Truck Axle Load Spectra Using Weigh-in-Motion Data

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To assure a smooth transition from the existing pavement design methods to the new mechanistic-empirical design method in the Indiana Department of Transportation, a study was conducted to create truck traffic inputs and axle load spectra of major interstate and state-owned highways in Indiana. The existing pavement design method is based on the equivalent single-axle loads (ESAL), which converts wheel loads of various magnitudes and repetitions to an equivalent number of "standard" or "equivalent" axle loads. The new design method uses axle load spectra as the measure of vehicle loads on pavements. These spectra represent the percentage of the total axle applications within each load interval for single, tandem, tridem, and quad axles. In this study, the truck traffic and axle load spectra were developed based on the historical traffic data collected at 47 sites with weigh-in-motion technology. The truck traffic information includes hourly, daily, and monthly distributions of various types of vehicles and corresponding adjustment factors, the distributions of the number of axles of each type of truck, the weights of the axles, the spaces between the axles, the proportions of vehicles on roadway lanes, and the proportions of vehicles in driving directions. This paper presents the truck traffic and axle load spectra generated from the weigh-in-motion sites as required by the new pavement design method.

INTRODUCTION

The values of equivalent single-axle loads (ESAL) have been used to represent the vehicle loads in pavement design (AASHTO 1993). To improve the pavement design procedures, a new method, called the Mechanistic-Empirical Pavement Design Guide (MEPDG) (NCHRP 2004), has been developed to use the axle load spectra to represent the vehicle loads in pavement design. These spectra represent the percentage of the total axle applications within each load interval for single, tandem, tridem, and quad axles. This new pavement design method is a mechanistic-empirical approach to designing pavement structures. It is a radical change from the ESAL based method. The axle load spectra approach quantifies the characteristics of traffic loads by directly using all individual axle loads, instead of converting them into ESAL values. Using axle load spectra as the traffic input, the MEPDG method is able to analyze the impacts of varying traffic loads on pavement and provide an optimal pavement structure design. In addition, the new method can be used to analyze the effects of materials and the impacts of seasons, to compare rehabilitation strategies, and to perform forensic analyses of pavement conditions. Although both approaches are based on the same data sources, the axle load spectra approach is more consistent with the state-of-the-practice method for traffic monitoring outlined in the Traffic Monitoring Guide (FHWA 2001).

To prepare the transition from equivalent single-axle loads to load spectra, many studies have been conducted by different states to analyze the effects of the new design method. Buchanan (2004) utilized the long-term pavement performance (LTPP) data from Mississippi sites to determine vehicle class distribution, monthly and hourly distribution factors, and axle load spectra. The truck traffic data in Mississippi showed that the single-trailer trucks comprised 70% of the truck traffic on interstates and four-lane highways. Also, single-unit trucks were the primary type of trucks on the low volume routes in Mississippi.

Li, Nantung, and Jiang (2005) performed primary analysis with Indiana's Weigh-in-Motion (WIM) data to identify the data needs and related issues for the truck traffic requirements of the MEPDG. They applied GIS and GPS technologies in managing WIM site information and database.

They also developed a special computer program for processing the large amount of WIM data. In the study, the truck traffic distributions were developed and were illustrated on a GIS map.

Al-Yagout et al. (2005) developed truck axle load spectra using the axle load data collected at WIM stations throughout Washington State. The project concluded that the developed load spectra are reasonable for pavement design. For single axles, they are comparable to the MEPDG defaults. For tandem and tridem axles, they are slightly more conservative than the defaults.

An Alabama study (Timm, Bower and Turochy 2006) evaluated different load spectra in terms of practical effects on resulting flexible pavement thickness design. The study concluded that statewide load spectra are warranted for use and will not adversely affect most pavement designs.

Haider and Harichandran (2007) presented a methodology for using truck weights and proportions on a highway to estimate individual axle load spectra for various axle configurations. Their study results showed that truck weights and proportions on a highway can be used to estimate individual axle load spectra for various axle configurations. They claimed that it was possible to develop reasonable relationships between truck weights and axle loads.

In a Canadian study (Swan et al. 2008), the truck traffic data, collected as part of periodic commercial traffic surveys, were used to obtain best possible default values for traffic input parameters required for the MEPDG. The researchers compared the default traffic data inputs included in the MEPDG software and the regional traffic data inputs developed in the study in terms of axle load spectra. They found that the axle load spectra from their study have a smaller number of heavily overloaded axles and the peaks between loaded and unloaded axles are more pronounced. They also found that the number and type of trucks, followed by the axle load spectra, have the predominant influence on the predicted pavement performance. The MEPDG contains several input parameters which do not have any significant influence on the predicted pavement performance, such as hourly traffic volume adjustment factors, and axle spacing.

In order to provide the traffic data input required by the MEPDG, the Indiana Department of Transportation (INDOT) made an effort to obtain truck traffic information from the traffic data collected through WIM stations. This paper presents the results of generated truck traffic information with respect to the requirements of the MEPDG. The characteristics of the truck traffic on Indiana highways include the traffic volumes of various types of trucks, the axle load spectra, axle spacing, and adjustment factors of truck traffic. The adjustment factors include hourly and monthly truck traffic adjustment factors, which are used to reflect the changes of truck traffic at different time periods.

WIM DATA PROCESSING

The INDOT WIM system consists of 47 WIM sites installed on interstate and other state-owned primary highways. The vertical loading applied to the pavement by a moving vehicle consists of two components: the static load and the dynamic load. The static load depends on the weight and the layout of the axles and tires of the vehicle. The dynamic load is generated by vibration of the vehicle. The following three types of WIM devices are used in Indiana:

- Bending Plate: WIM systems utilize plates with strain gauges bonded to the underside. As a vehicle passes over the bending plate, the system records the strain measured by the strain gauge and calculates the dynamic load. The static load is estimated using the measured dynamic load and calibration parameters.
- Piezoelectric Sensor: WIM systems utilize piezo sensors to detect a change in voltage caused by pressure exerted on the sensor by an axle and measure the axle's weight. As a vehicle passes over the piezo sensor, the system records the electrical charge created by the sensor and calculates the dynamic load. The static load is estimated using the measured dynamic load and calibration parameters.
- Load Cell: WIM systems utilize a single load cell with two scales to detect an axle and weigh both the right and left side of the axle simultaneously. As a vehicle passes over the

two load cell, the system records the weights measured by each scale and sums them to obtain the axle weight.

Among the 47 WIM sites, 23 of them are Piezoelectric Sensor WIM systems, 13 are Bending Plate WIM systems, and the rest are Load Cell WIM systems. All WIM raw data have to be screened for errors before they are put in a database in the form of a monthly traffic data file. A monthly WIM data file generally consists of all traffic information that is necessary to generate traffic summary reports. The traffic database from the WIM measurements is used for many purposes, including the Long-Term Pavement Performance (LTPP) monitoring, pavement design, truck weight enforcement by Indiana State Police (ISP), and WIM system improvements by the contractors. As part of this study, the database is utilized to develop traffic design inputs for the MEPDG.

The WIM raw data files are binary data files containing all traffic information. In general, the binary data files must be converted into American Standard Code for Information Interchange (ASCII) data files that are usually very large in size. In reality, the potential damages to pavement structures caused by passenger vehicles are negligible. Both the AASHTO method and the MEPDG do not consider the effects of passenger vehicles on pavement structure and only take into account the trucks of Class 4 to Class 13 as defined by FHWA (2001). Therefore, in order to process traffic data for pavement design, pavement engineers only focus on truck traffic information, rather than all of the traffic information in the binary WIM data files.

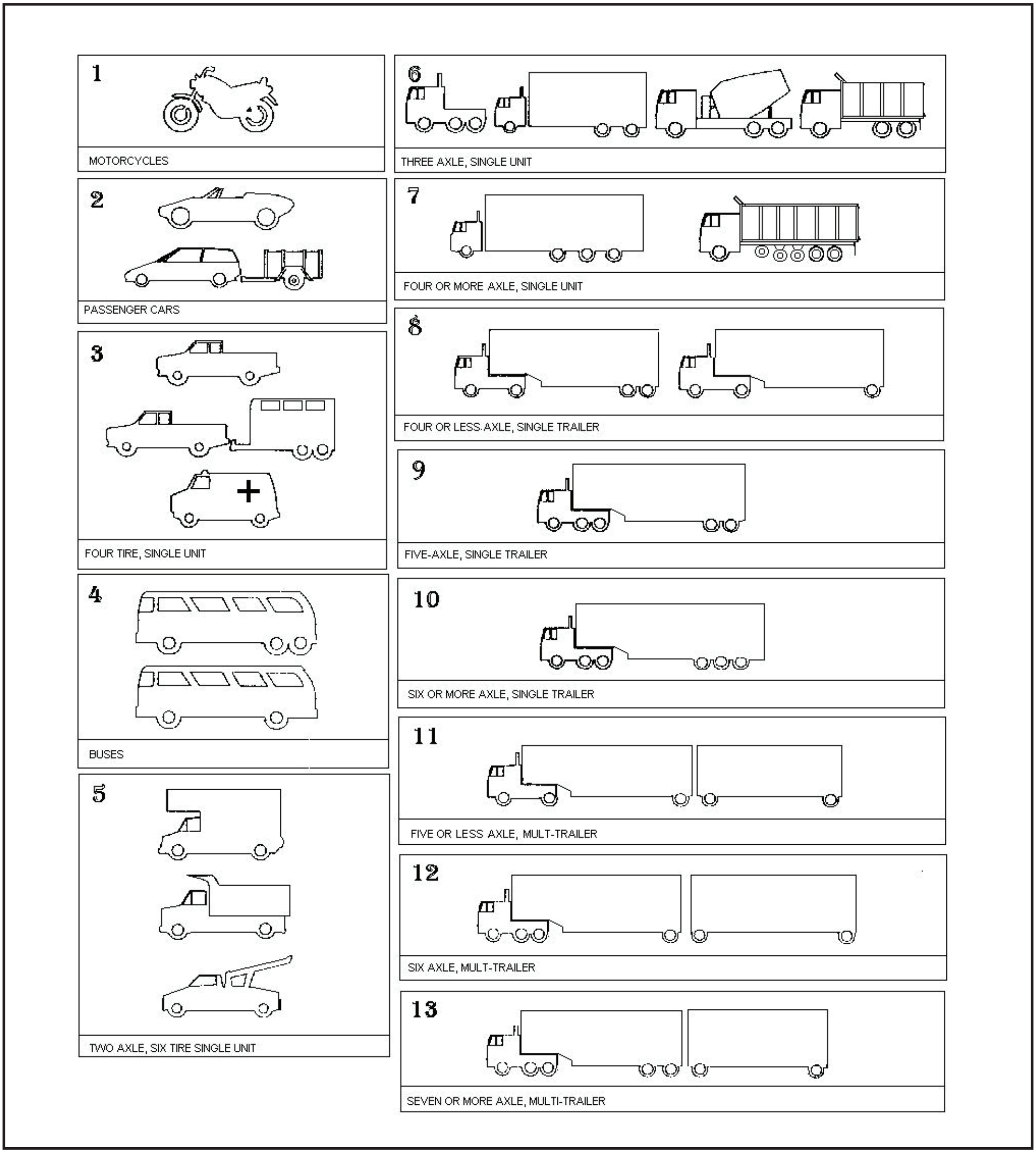
In order to extract the truck traffic information from the binary WIM data files, the authors utilized the vendor’s software to generate the ASCII raw vehicle report (IRD 1999). An ASCII raw vehicle report consists solely of the truck traffic information, including time, lane number, vehicle class, speed, axle weight, and axle spacing. Since an ASCII raw vehicle report file is also large in size, a Visual Basic® computer program was developed to generate traffic inputs required by the MEPDG from the ASCII file.

TRUCK TRAFFIC AND VEHICLE AXLE LOAD SPECTRA

The FHWA vehicle classification defines 13 types of vehicles as shown in Figure 1. Since the first three types of vehicles are not considered in pavement design, only vehicles in Classes 4 through 13 are included in the axle load spectra. The five-year WIM data between 2000 and 2004 were used for the data processing and analysis. All of the required traffic inputs for the MEPDG were obtained from the 47 WIM stations. To illustrate the axle load spectra, the WIM station on I-74 (at reference marker 169.77) is selected in this paper to present the processed traffic data. There are four lanes (two lanes in each direction) at the I-74 site. In the eastbound direction, Lane 1 and Lane 2 represent the driving lane and the passing lane, respectively. In the westbound direction, Lane 3 and 4 represent the driving lane and the passing lane, respectively. The traffic inputs for the MEPDG include the following:

- Average annual daily truck traffic;
- Truck volume monthly adjustment factors;
- Truck volume lane distribution factors;
- Truck volume directional distribution factors;
- Truck volume class distributions;
- Traffic volume hourly distribution factors;
- Single-axle load distributions;
- Tandem-axle load distributions;
- Tridem-axle load distributions;
- Quad-axle load distributions;
- All-axle load distributions;
- Average axle weight (kips) and average axle spacing (inches) (Note: 1.0 kip = 1,000 pounds);
- Average number of axle types.

Figure 1: FHWA Vehicle Classifications



An important traffic input for the MEPDG is the average annual daily truck traffic (AADTT). The obtained values of the truck traffic are in the forms of average monthly daily truck traffic (AMDTT) and average hourly truck traffic (AHTT) of a year. Table 1 presents the monthly AMDTT values at the I-74 WIM station. It should be noted that the average values shown in the last row of Table 1 are the values of AADTT of the corresponding lanes. With the AMDTT values, the monthly adjustment factors (MAF) can be calculated by the following equation (NCHRP 2004):

$$(1)\quad \mathrm{MAF}_i = \frac{\mathrm{AMDTT}_i}{\sum_{j=1}^{12} \mathrm{AMDTT}_j} \times 12$$

where:

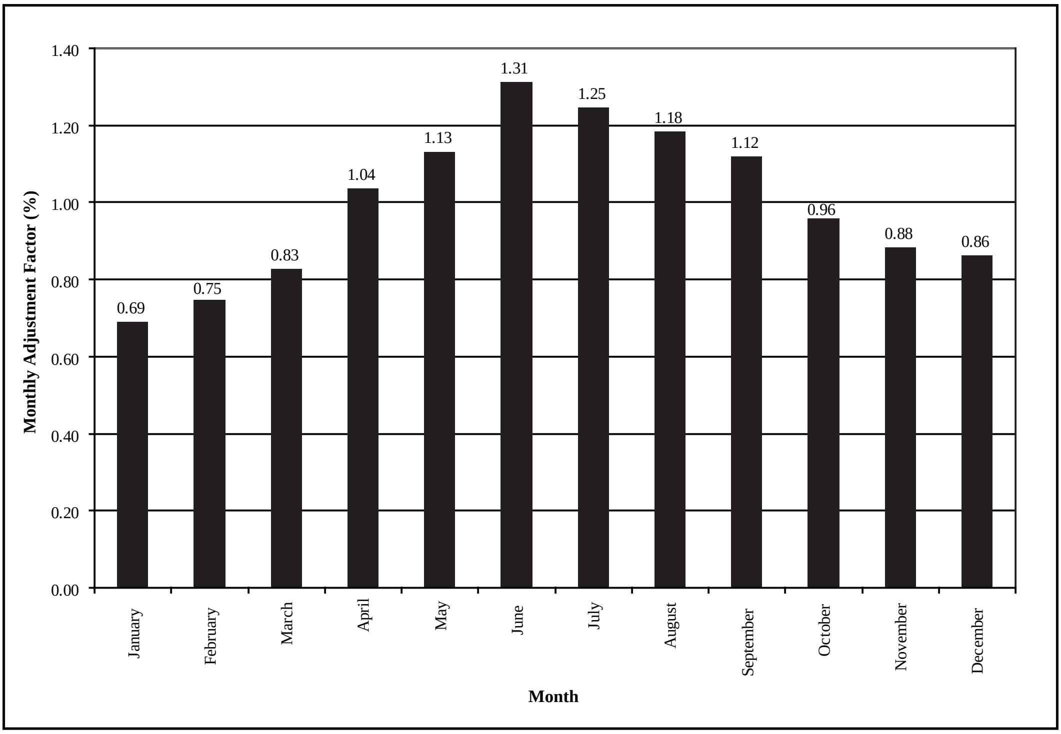
MAF_i: monthly adjustment factor for month i.
$AMDTT_i$: average monthly daily truck traffic for month i.

Table 1: Monthly Truck Traffic at I-74 WIM Site

	Monthly ADTT			
	Lane 1	**Lane 2**	**Lane 3**	**Lane 4**
January	2557	344	2462	489
February	2840	385	2616	492
March	3136	418	2915	555
April	3398	452	3317	1616
May	3715	458	3919	1494
June	4353	515	4660	1599
July	3920	529	4518	1614
August	3739	524	4153	1627
September	3562	488	3886	1551
October	3073	440	3116	1500
November	2802	428	2814	1454
December	2632	464	2689	1538
Average	**3311**	**454**	**3422**	**1294**

Figure 2 shows the monthly adjustment factors calculated with the data in Table 1. The MEPDG uses MAF values as an input to reflect the monthly and seasonal effects of truck traffic on pavement performance. Therefore, MAF values will certainly affect the results of pavement designs.

Figure 2: Monthly Adjustment Factors



Similarly, the values of AHTT were also obtained. The values of hourly truck volumes at the I-74 WIM station are graphically shown in Figure 3. The variations of the hourly truck volumes at the site can be clearly seen in the graph. Based on the average hourly truck traffic, the hourly distributions factors were calculated as shown in Figure 4. The hourly distribution factors are the percentages of truck traffic at each hour out of the total truck volume during a 24-hour period.

Figure 3: Hourly Truck Volumes

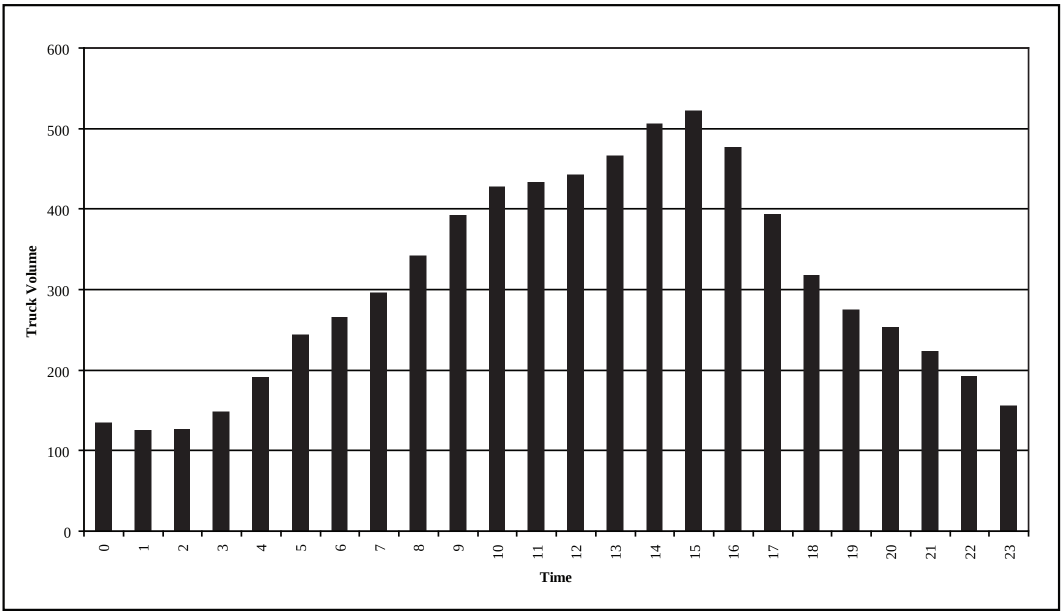
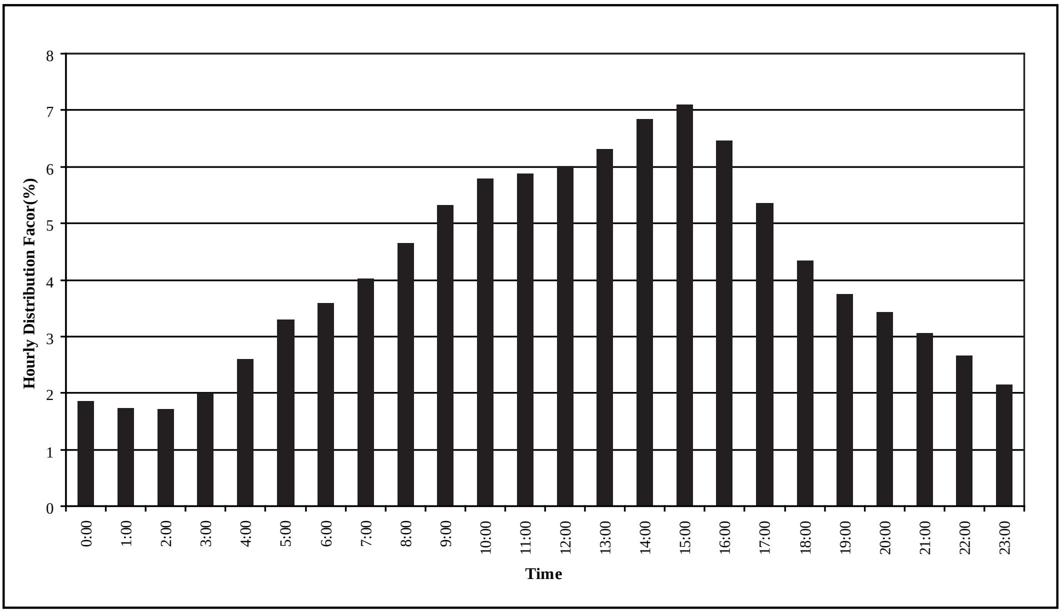


Figure 4: Hourly Distribution Factors of Truck Traffic



In addition to the AADTT, the MEPDG requires information on the components of truck traffic based on the FHWA vehicle classifications. The truck components are represented by the percent of each truck type. The truck classifications at the I-74 WIM station are illustrated in Figure 5, where Ci means the ith vehicle class of the FHWA vehicle classifications and C0 represents unclassified vehicles. The unclassified vehicles are those that the WIM device failed to identify their vehicle types based on the integrated criteria. They include only the number of unclassified vehicles without any other measurements such as axle loads and axle spaces. The quantities of unclassified vehicles have great effect on pavement design. There are many possible reasons for a vehicle not to be classified, such as vehicle tailgating, lane changing, and irregular vehicle size. An unreasonably large value of unclassified vehicles (C0) usually indicates that the WIM device is not working properly. Currently, there are no specified threshold values for normal range of unclassified vehicles. The truck classifications in Figure 5 indicate that most of the trucks belong to Class 9, followed by Class 5 vehicles. In fact, this is also true for all of the 47 WIM sites in Indiana. Li et al. (2005) found that the volume of Class 9 vehicles and the total ESAL value on Indiana highways have a highly correlated linear relationship. The truck volumes of the vehicle types in each month are presented in Table 2.

Figure 5: Truck Classification Distribution

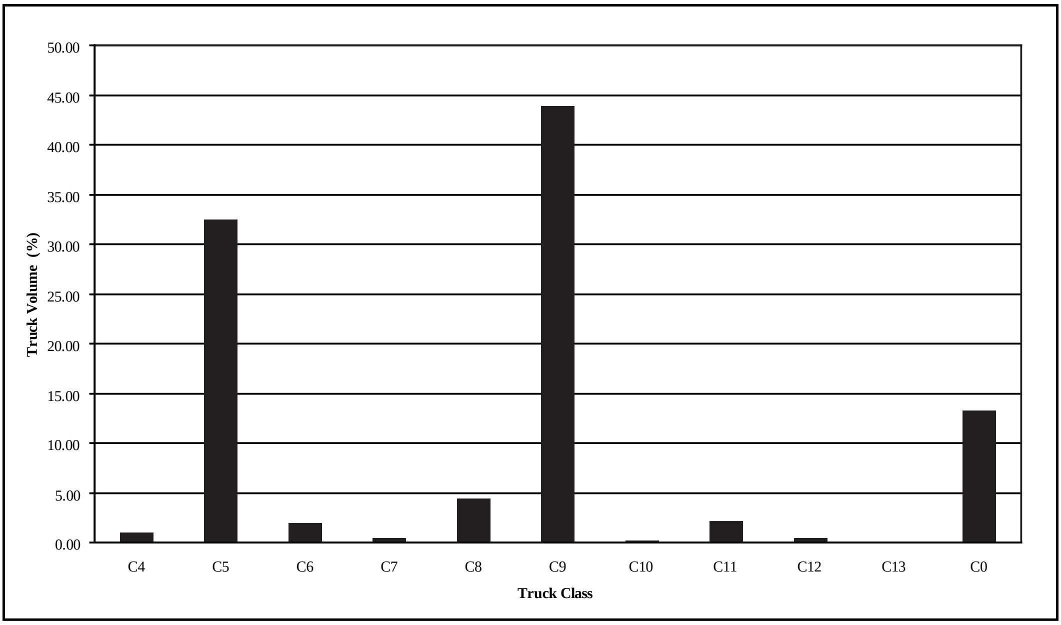


Table 2: Average Monthly Daily Truck Volumes

Month	Vehicle Class										
	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C0
Jan	32	1006	233	21	240	2420	10	124	19	5	1743
Feb	39	1159	208	18	227	2418	9	119	18	2	2118
Mar	51	1581	340	13	372	2782	10	149	22	0	1704
Apr	103	2886	128	21	389	4195	17	201	41	0	803
May	113	3793	131	48	434	3971	12	191	40	0	853
Jun	108	4820	142	53	490	4282	17	207	44	0	963
Jul	97	4656	130	57	480	3957	13	193	39	0	959
Aug	102	3841	141	50	469	4228	17	202	40	0	953
Sep	107	3353	122	54	445	4261	16	197	41	0	891
Oct	102	2297	119	43	361	4150	14	199	41	0	803
Nov	94	1851	123	31	287	4141	15	185	39	0	732
Dec	76	1772	123	27	267	3836	12	174	33	0	1004
Total	**1023**	**33016**	**1941**	**435**	**4461**	**44640**	**162**	**2141**	**416**	**8**	**13524**

Distributions of truck traffic on roadway lanes and in travel directions are also required by the MEPDG. The total truck volume and truck volumes on the four lanes at the I-74 WIM station are depicted in Figure 6. Based on the data in Figure 6, the lane distribution factors of truck traffic can be computed as shown in Figure 7. A lane distribution factor in Figure 7 is the proportion of the vehicles on the travel lane. For example, the lane distribution factor of 0.94 for Class 9 vehicles in the east bound direction means that 94% of the Class 9 vehicles were on the driving lane and 6% of the vehicles were on the passing lane. Similarly, the directional distribution factors can be obtained as shown in Figure 8. A directional distribution factor represents the higher percent of a given vehicle type among the two travel directions of the roadway. For example, in Figure 8 the directional distribution factor of 0.92 for C7 means that 92% of the Class 7 vehicles traveled in one direction of the roadway and 8% of the Class 7 vehicles traveled in the opposite direction of the roadway.

Through processing the WIM data files, the values of average axle weights, average axle spacing, and average numbers of axle types were obtained as part of the requirements for the MEPDG. Table 3 presents these values for the I-74 WIM station. In the table, Wi denotes the average weight of the ith axle of the vehicle class, Sij is the average spacing between the ith and jth axles, and the low part of the table shows the average numbers of a particular type of axles (single, tandem, etc.) per vehicle. For example, from Table 3 the following values can be seen for the vehicles in Class 4:

- They have three axles with average weights of 14.70 kips (W1), 13.88 kips (W2), and 9.26 kips (W3).
- The average axle spacing is 23.18 inches between the first and second axles (S12) and 3.70 inches between the second and third axles (S23).
- The average number of single axles is 1.78 per vehicle, and the average number of tandem axles is 0.22 per vehicle.

The number of average axle weights in the table implies the maximum number of axles in each class of trucks. As indicated in Table 3, the maximum number of axles of Class 5 vehicles is two because there are only two weights (W1 and W2), while the maximum number of axles of Class 13 vehicles is nine because there are nine weights (W1 through W9).

Figure 6: Truck Traffic Distributions on Highway Lanes

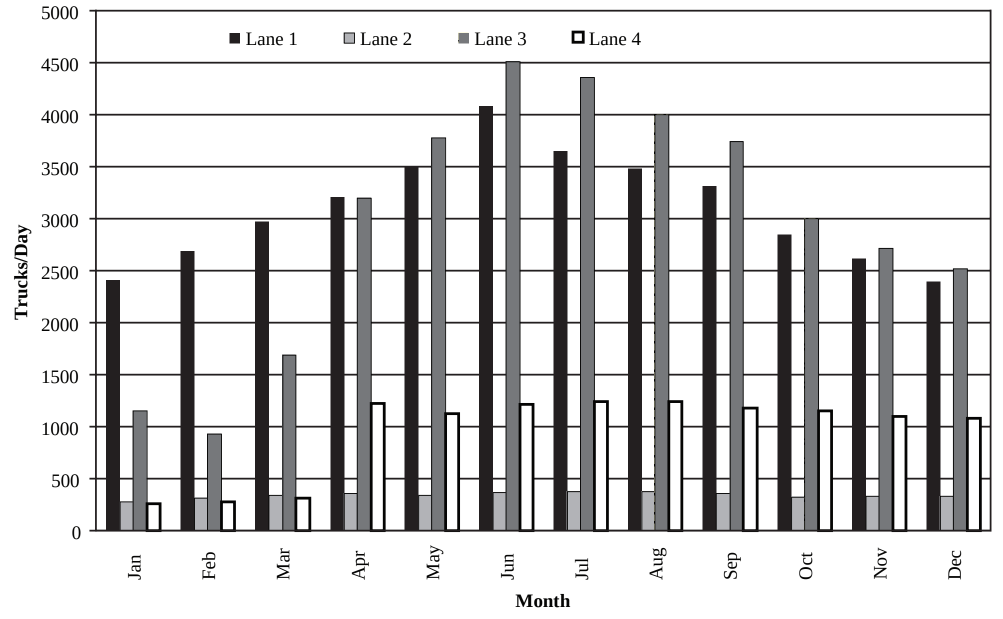


Figure 7: Lane Distribution Factors

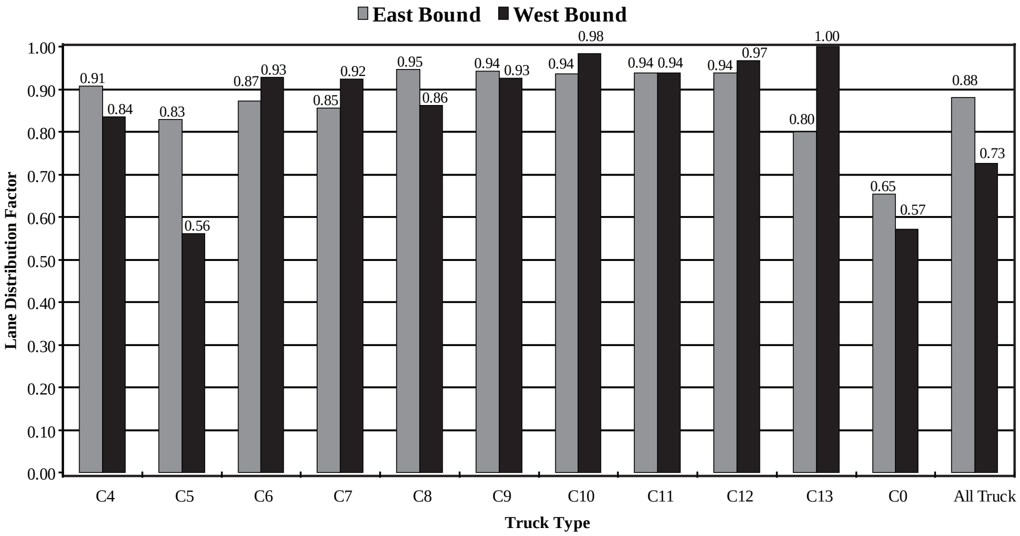
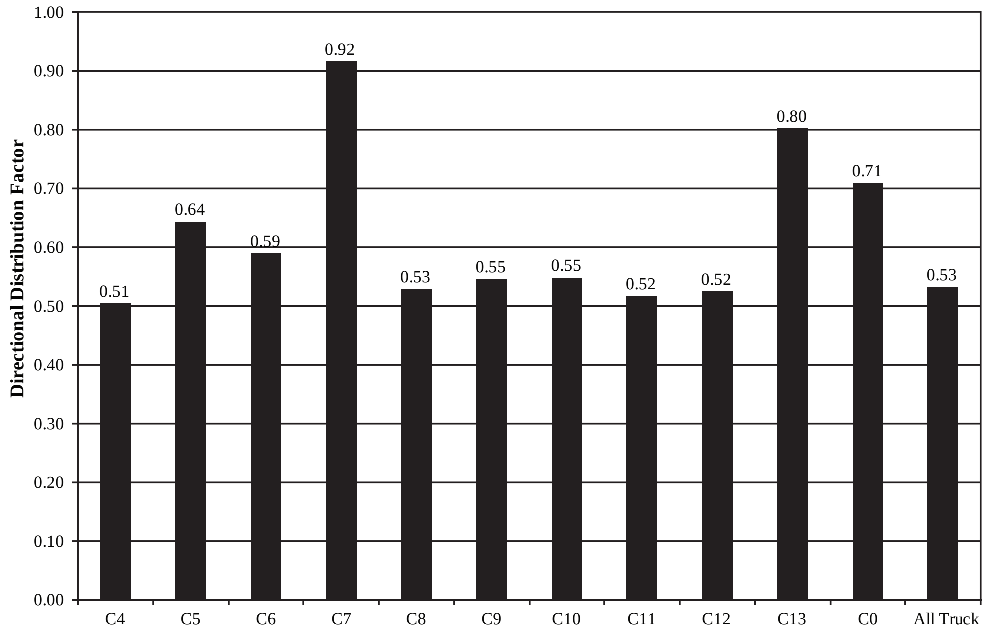


Figure 8: Truck Traffic Directional Distribution Factors



The magnitudes of axle loads are a major parameter for pavement design. To quantify axle loads, the MEPDG requires the axle load distributions for all classes of trucks. The axle load distributions are the percentages of axle loads in specified weight intervals, such as zero to three kips, three to four kips, and four to five kips. The axle load distributions include the axle weights for all-axle loads, single-axle loads, tandem-axle loads, tridem-axle load, quad-axle loads, quinate-axle loads, and hex-axle loads. It should be pointed out that the MEPDG does not require the information on axle load distributions for quinate-axle and hex-axle loads. However, because the Indiana WIM data contain the values of quinate-axle and hex-axle loads, it would not require any extra effort to include these two types of axle loads in the computer program used in this study to extract and calculate axle load distributions. Thus, it was decided to generate the distributions for these axle loads as well for possible future use. The values of the all-axle load and single-load axle load distributions are shown in Tables 4 and 5, respectively. The values in the two tables are the percentages of the vehicle classes with axle loads within the given load ranges. For example, in Table 4, the value corresponding to vehicle class C4 and axle load range 0-3 is 3.82, meaning that 3.82% of Class 4 vehicles have axle loads of less than three kips. Similarly, in Table 4 the value 5.37 (corresponding to C4 and axle load 3-4) indicates that 5.37% of Class 4 vehicles have axle load between three kips and four kips.

An attempt was made to compare Indiana's truck load distributions with other states' truck load distributions. However, it was found that the load spectra were unique and different from site to site even within the same state and it was difficult to make a meaningful comparison of the truck load spectra among different states. Thus, such comparisons were not conducted in this study.

Table 3: Average Axle Weight (kips), Axle Spacing (inches), and Number of Axle Types by Vehicle Classes

	Vehicle Classes									
Weight	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**
W1	14.70	5.33	7.78	9.44	8.51	8.44	8.08	8.60	9.62	6.66
W2	13.88	5.12	6.20	7.55	10.98	6.14	5.81	12.21	7.23	5.59
W3	9.26		6.20	7.51	10.03	6.00	5.71	12.88	7.66	5.77
W4				7.73	6.64	5.76	4.97	11.25	9.71	5.19
W5				4.39		5.73	4.90	11.31	11.35	5.57
W6							5.24		8.74	7.08
W7							2.47			6.31
W8										7.79
W9										4.20
Spacing										
S12	23.18	13.06	18.97	5.68	12.35	13.88	13.85	10.42	12.58	9.45
S23	3.70		3.24	20.55	18.41	3.93	3.64	17.62	4.05	5.28
S34				3.35	14.91	27.22	19.77	7.94	17.31	7.50
S45				1.85		4.21	5.67	17.98	8.78	10.96
S56							3.50		18.88	6.27
S67							1.88			5.62
S78										5.09
S89										3.58
Axle Type										
Single	1.78	2.00	1.00	1.75	2.36	1.27	1.05	4.74	3.72	2.10
Tandem	0.22		1.00	0.75	0.63	1.86	1.03	0.08	1.09	1.08
Tridem				0.12			0.92	0.03	0.02	0.45
Quad				0.12			0.02		0.01	0.15
Quinate										0.05
Hex							0.01			0.14

EFFECTS OF UNCLASSIFIED VEHICLES

As previously mentioned, the WIM data contained vehicles that could not be classified by the WIM device. The possible reasons for this include vehicle tailgating, lane changing, irregular vehicle size, and WIM equipment problems. These unclassified vehicles could be any types of vehicles, including passenger cars, buses, and trucks. How to deal with these vehicles will undoubtedly affect pavement designs because it will result in different truck traffic inputs. For instance, if all of the unclassified vehicles are treated as trucks, the total axle loads will be overestimated. On the other hand, if they are not included in the truck traffic, the total axle loads will be underestimated. One reasonable way to deal with this is to assign them to different vehicle groups, but to do this one needs to know the proportions of the vehicle types in the unclassified vehicles. However, the proportions are currently not available.

In order to analyze the effects of unclassified vehicles, various amounts of unclassified vehicle volumes were added to the total truck volumes of the five-year WIM data to examine the patterns of the truck traffic. If all of the unclassified vehicles are disregarded, then the total truck volumes and the truck volumes of individual types of trucks are as shown in Figure 9. The regression equation of the total AADTT values is also shown in the figure. If 100% of the unclassified vehicles are vehicles, the total AADTT will be increased by the amount of unclassified vehicles (C0). Similarly, analysis can be done by adding 50% and 25% of the unclassified vehicles to the truck volumes. The

Table 4: All-Axle Load Distribution (Percentages) for Each Truck Class

Axle Load Range (kips)	Vehicle Classes									
	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
0-3	3.82	26.47	42.37	20.17	18.02	28.43	25.52	9.90	5.83	7.05
3-4	5.37	12.00	15.60	17.67	9.92	21.70	13.50	13.65	14.10	18.47
4-5	7.62	7.12	12.37	14.33	8.98	14.45	11.82	14.30	16.78	14.75
5-6	9.40	5.87	9.37	10.83	7.40	10.30	10.58	13.42	13.37	14.67
6-7	14.87	5.45	6.33	7.20	6.67	6.92	7.68	10.45	9.83	8.52
7-8	14.33	7.15	3.93	6.27	6.27	4.50	5.83	7.87	6.60	5.97
8-9	11.18	2.88	2.77	5.07	5.22	2.90	4.83	6.28	5.32	7.83
9-10	7.53	2.43	2.07	4.10	4.37	2.02	3.85	4.90	4.12	4.55
10-11	6.12	1.18	1.53	2.67	3.42	1.52	3.28	3.55	3.03	3.30
11-12	4.12	4.63	1.00	1.80	3.10	1.15	2.72	3.05	2.43	3.48
12-13	2.18	2.17	0.57	1.37	2.40	0.88	1.85	2.47	1.98	2.12
13-14	2.13	2.17	0.33	1.37	1.98	0.65	1.42	1.68	1.50	1.67
14-15	1.22	4.88	0.27	1.37	1.80	0.50	1.22	0.90	1.22	1.47
15-16	1.58	1.53	0.13	0.97	1.63	0.38	0.95	1.17	1.13	1.00
16-17	1.32	0.65	0.20	0.90	1.43	0.30	0.65	0.63	0.90	1.18
17-18	1.32	1.28	0.07	1.10	1.05	0.22	0.50	0.98	0.80	0.82
18-19	0.50	3.12	0.03	0.33	1.12	0.20	0.45	0.77	0.68	0.42
19-20	0.05	1.85	0.03	0.43	0.97	0.17	0.35	0.72	0.67	0.25
20-21	0.92	0.00	0.00	0.40	0.88	0.13	0.33	0.17	0.60	0.27
21-22	0.80	0.00	0.00	0.17	0.90	0.10	0.27	0.30	0.55	0.37
22-23	0.03	0.00	0.00	0.27	0.80	0.10	0.18	0.27	0.48	0.28
23-24	0.85	0.63	0.00	0.03	0.72	0.10	0.17	0.27	0.48	0.13
24-25	0.25	0.00	0.00	0.07	0.72	0.08	0.12	0.27	0.47	0.22
25-26	0.05	0.00	0.00	0.03	0.55	0.08	0.12	0.17	0.42	0.03
26-27	0.25	0.00	0.00	0.13	0.53	0.08	0.08	0.05	0.37	0.03
27-28	0.00	0.00	0.00	0.00	0.48	0.08	0.03	0.03	0.38	0.02
28-29	0.00	0.00	0.00	0.03	0.43	0.05	0.03	0.05	0.35	0.02
29-30	0.00	1.27	0.00	0.00	0.50	0.05	0.03	0.03	0.35	0.07
30-31	0.00	0.00	0.00	0.07	0.45	0.05	0.03	0.08	0.33	0.00
31-32	0.00	0.00	0.00	0.00	0.45	0.05	0.00	0.10	0.32	0.00
32-33	0.00	0.00	0.00	0.00	0.38	0.05	0.02	0.00	0.30	0.00
33-34	0.00	0.00	0.00	0.00	0.38	0.03	0.02	0.00	0.27	0.00
34-35	0.00	1.85	0.00	0.00	0.40	0.03	0.00	0.00	0.25	0.00
35-36	0.00	0.00	0.00	0.00	0.30	0.03	0.03	0.00	0.25	0.00
36-37	0.00	0.00	0.00	0.00	0.35	0.03	0.02	0.03	0.22	0.00
37-38	0.00	1.27	0.00	0.00	0.35	0.03	0.00	0.02	0.22	0.00
38-39	0.00	0.00	0.00	0.00	0.35	0.02	0.00	0.00	0.22	0.00
39-40	0.00	0.00	0.00	0.00	0.33	0.03	0.00	0.02	0.18	0.00
40-41	1.23	1.27	0.00	0.10	2.52	0.28	0.12	0.22	1.48	0.02

Table 5: Single-Axle Load Distribution (Percentages) for Each Truck Class

Axle Load Range (kips)	Vehicle Classes									
	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
0-3	0.59	51.34	14.72	2.07	5.61	3.52	2.31	0.14	0.23	0.20
3-4	0.38	20.56	3.28	4.30	12.30	3.34	2.17	4.30	4.08	7.08
4-5	0.47	10.23	4.11	3.48	10.63	3.79	3.15	6.14	6.09	9.96
5-6	0.89	5.09	4.65	3.44	9.59	4.60	4.61	7.67	8.62	9.76
6-7	8.06	3.22	5.25	3.42	9.13	5.92	7.22	8.84	9.55	9.18
7-8	14.35	2.27	6.81	4.00	9.24	8.29	10.22	10.38	11.30	9.07
8-9	14.31	1.69	9.18	4.83	8.52	11.77	14.19	11.28	12.01	9.43
9-10	12.70	1.25	11.13	5.96	7.00	15.83	17.16	10.33	11.71	9.59
10-11	10.64	0.90	10.00	6.34	5.27	15.00	15.03	8.87	9.89	9.43
11-12	8.58	0.64	7.18	7.19	3.88	10.13	10.29	6.93	7.74	6.24
12-13	6.45	0.46	4.95	7.59	2.93	5.77	5.41	5.45	5.50	4.64
13-14	4.74	0.34	3.42	7.78	2.32	3.00	2.42	4.60	4.00	3.24
14-15	3.54	0.27	2.56	7.16	1.93	2.04	1.55	3.69	2.72	2.05
15-16	2.64	0.22	2.03	6.75	1.63	1.68	1.09	2.95	1.90	1.81
16-17	2.07	0.18	1.75	5.92	1.33	1.40	0.79	2.27	1.31	2.13
17-18	1.59	0.15	1.52	5.48	1.12	1.09	0.58	1.64	0.99	2.18
18-19	1.25	0.13	1.29	4.35	0.92	0.79	0.43	1.18	0.65	1.35
19-20	0.97	0.11	1.04	3.00	0.75	0.54	0.30	0.84	0.49	0.54
20-21	0.87	0.10	0.90	1.74	0.64	0.37	0.23	0.59	0.27	0.43
21-22	0.65	0.09	0.73	1.11	0.52	0.25	0.17	0.38	0.25	0.32
22-23	0.50	0.08	0.61	0.72	0.45	0.18	0.12	0.26	0.13	0.29
23-24	0.43	0.07	0.51	0.61	0.39	0.13	0.11	0.17	0.10	0.21
24-25	0.38	0.07	0.41	0.42	0.35	0.10	0.08	0.13	0.08	0.17
25-26	0.31	0.06	0.34	0.35	0.31	0.08	0.07	0.11	0.05	0.14
26-27	0.25	0.06	0.29	0.27	0.28	0.07	0.05	0.08	0.04	0.07
27-28	0.25	0.05	0.24	0.21	0.26	0.05	0.05	0.09	0.04	0.08
28-29	0.20	0.05	0.21	0.28	0.24	0.04	0.04	0.08	0.04	0.09
29-30	0.22	0.05	0.17	0.17	0.22	0.04	0.03	0.07	0.03	0.05
30-31	0.14	0.04	0.14	0.14	0.21	0.03	0.03	0.04	0.03	0.05
31-32	0.16	0.04	0.11	0.16	0.19	0.02	0.02	0.05	0.02	0.05
32-33	0.18	0.03	0.08	0.13	0.18	0.02	0.02	0.04	0.02	0.03
33-34	0.11	0.03	0.06	0.13	0.17	0.02	0.01	0.05	0.02	0.03
34-35	0.12	0.03	0.05	0.08	0.16	0.02	0.01	0.03	0.02	0.02
35-36	0.11	0.02	0.04	0.07	0.15	0.01	0.01	0.04	0.02	0.01
36-37	0.10	0.01	0.04	0.06	0.13	0.01	0.01	0.03	0.02	0.02
37-38	0.10	0.01	0.03	0.09	0.12	0.01	0.01	0.03	0.01	0.01
38-39	0.12	0.01	0.03	0.05	0.12	0.01	0.00	0.03	0.01	0.01
39-40	0.10	0.01	0.03	0.04	0.11	0.01	0.01	0.02	0.01	0.01
40-41	0.54	0.06	0.15	0.15	0.72	0.05	0.03	0.17	0.03	0.03

truck traffic patterns and regression equations with 100%, 50%, and 25% of included unclassified vehicles are plotted in Figures 10, 11, and 12, respectively.

It is apparent that the truck volumes, patterns, and regression equations are all significantly different when different amounts of unclassified vehicles are included in the truck traffic. Consequently, pavement designs with these different truck volumes will certainly be very different. Therefore, it is essential to obtain more accurate estimation of proportions of different types of vehicles in the unclassified vehicle category. To determine the components of unclassified vehicles, research is being undertaken using image processing techniques to study the patterns of unclassified vehicles recorded by WIM devices. It is hoped that the study will yield useful results to improve the truck traffic inputs for the MEPDG.

It should be pointed out that it is desirable to have a better understanding of the effects of unclassified vehicles on pavement performance. However, this study dealt with only the truck traffic input for the new design method and the analysis of the effects of unclassified vehicles on pavement performance was not performed because it was outside the scope of this study.

Figure 9: Average Daily Truck Traffic (no unclassified vehicles)

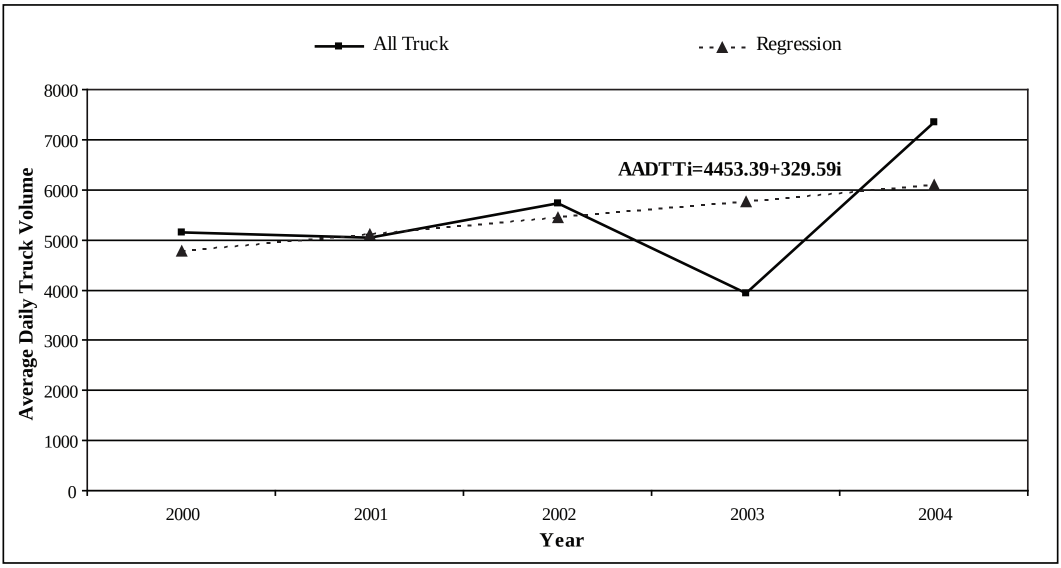


Figure 10: Average Daily Truck Traffic (including all unclassified vehicles)

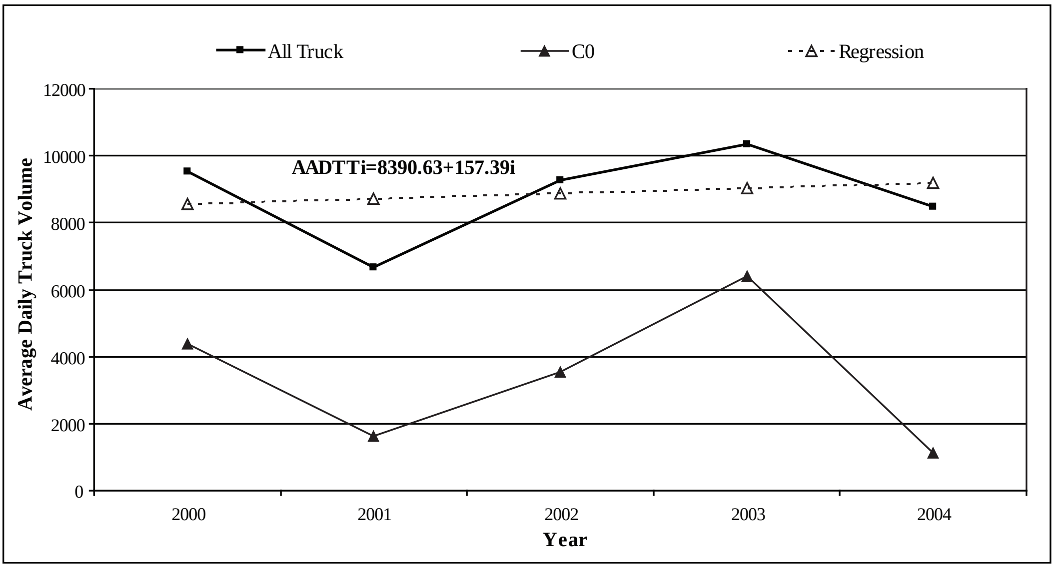


Figure 11: Average Daily Truck Traffic (including 50% unclassified vehicles)

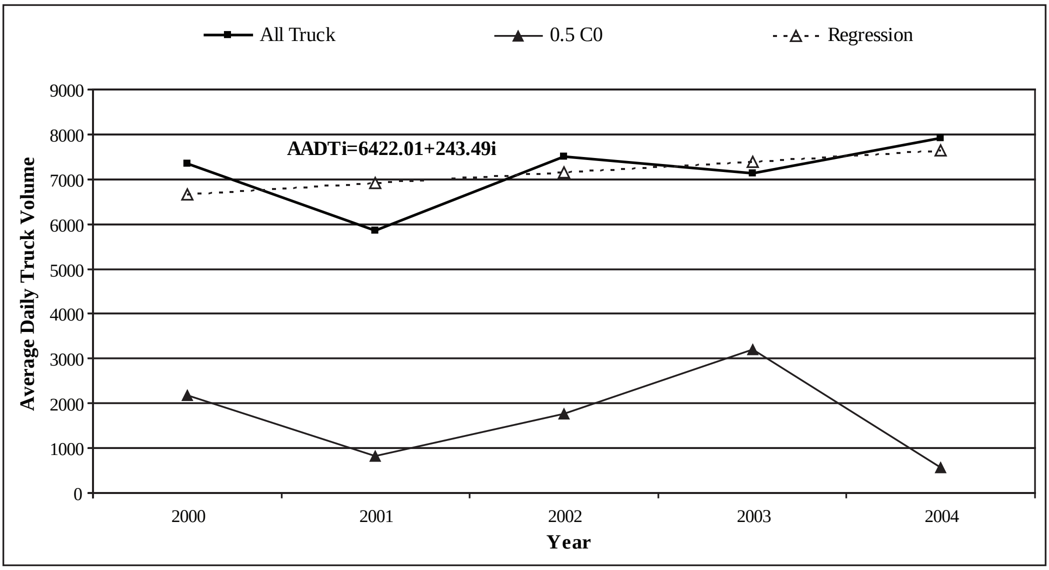
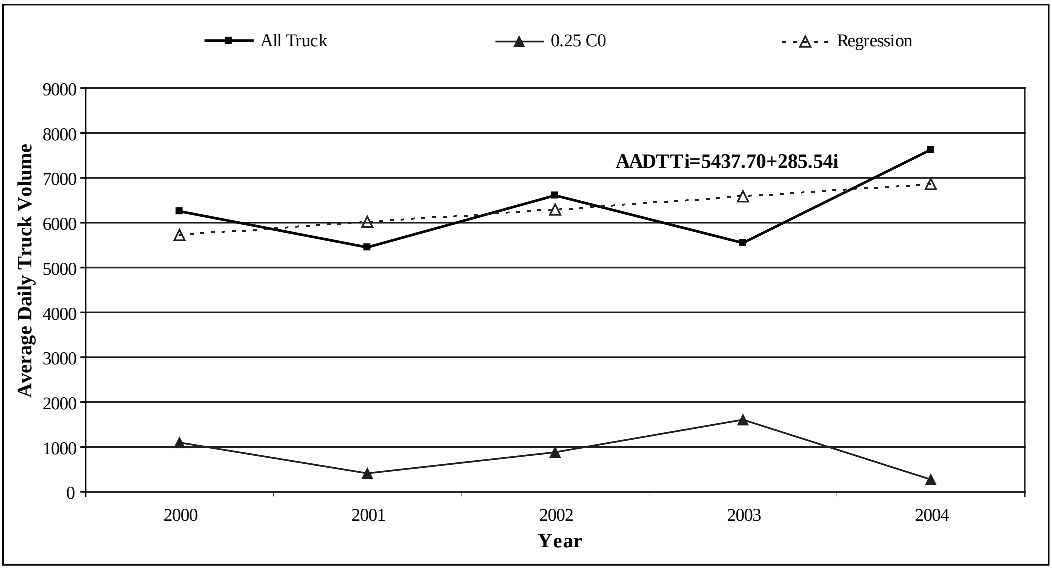


Figure 12: Average Daily Truck Traffic (including 25% unclassified vehicles)



CONCLUSIONS

In order to satisfy the requirements of the MEPDG, it is essential to prepare the truck traffic inputs because truck traffic is the most important requirement for the new design method. INDOT has made a great effort to retrieve the required traffic information from the stored WIM data. As presented in this paper, a Visual Basic computer program was developed and was successfully utilized to obtain the necessary traffic information for the new pavement design method from the WIM data. The truck traffic data include average annual daily truck traffic, average monthly and hourly truck traffic, adjustment factors, axle load spectra, and axle weight and spacing values. The truck traffic can be expressed in individual vehicle types as well as in combined truck traffic values. It was found that the WIM data contained a noticeable amount of unclassified vehicles, which would affect pavement designs if their patterns and components could not be reasonably identified. A study is being undertaken by INDOT to find the causes for recording vehicles as unclassified by the WIM devices. It is believed that the ongoing study will provide tools to improve the quality of truck traffic inputs from the INDOT WIM data.

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