Lies, Damned Lies, and Traffic Forecasting

Dr. David H. Timm and Dr. David E. Newcomb

Benjamin Disraeli once commented that in politics there are three kinds of lies: lies, damned lies, and statistics. This pessimistic viewpoint could be translated into the arena of pavement design and highlight the difficulty in characterizing the most important design variable—traffic.

Pavements, after all, are designed to carry traffic and while we can, with some accuracy, measure what is on the road today it can be extremely difficult to forecast with any certainty what will be on the road over the lifespan of the pavement. In addition to forecasting, the designer must account for the many different types of vehicles, weights, axle configurations, and tire pressures. In the past, this has been accomplished using equivalency factors to determine the number of equivalent single axle loads (ESALs). However, as mechanistic-empirical (M-E) design methods become more common, there is a push toward using load spectra. This article, the fourth in a series on M-E based design methods, will focus on changes in traffic characterization.

"First get the facts, then you can distort 'em as much as you want." — Mark Twain

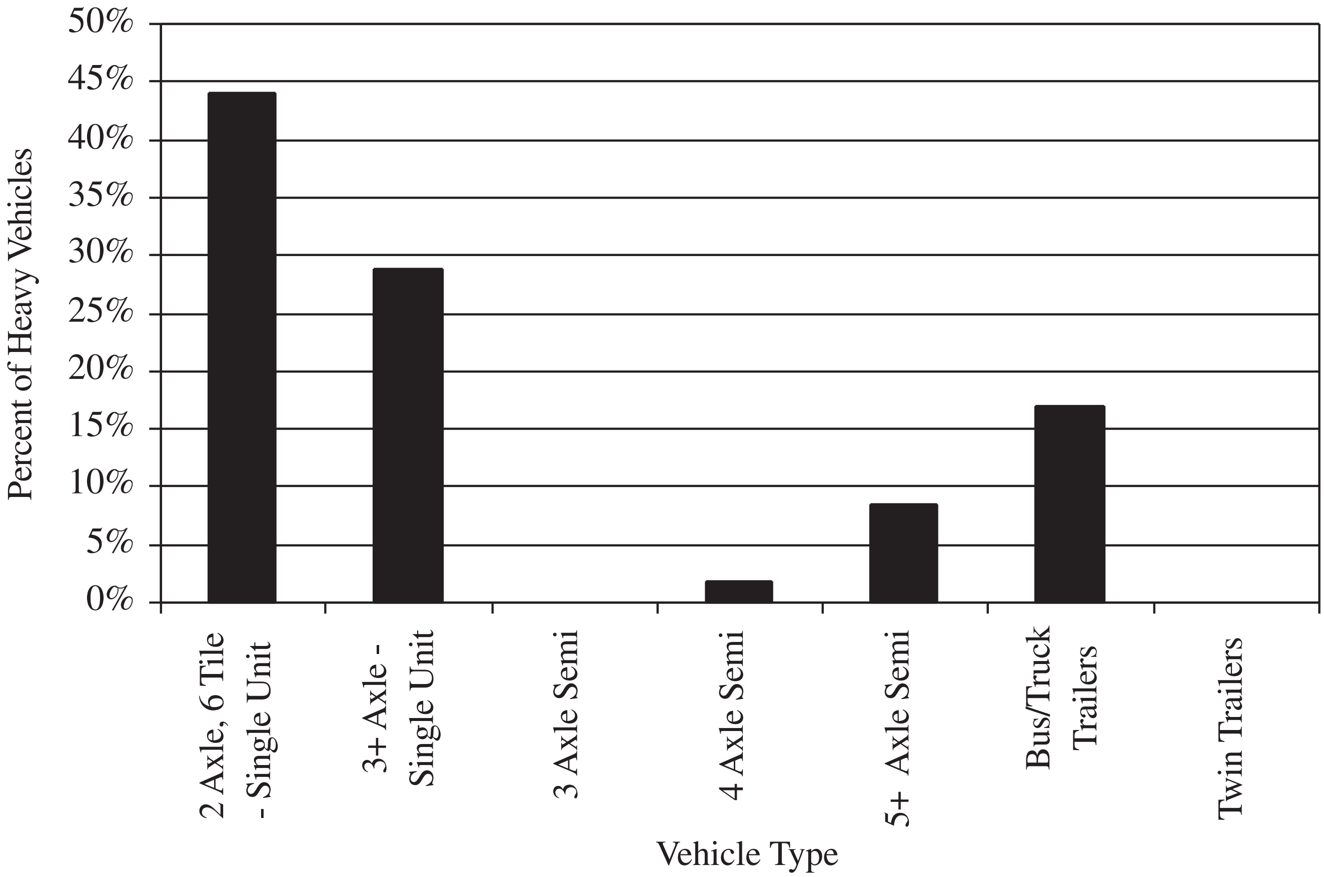
Regardless of how traffic is characterized for design purposes, there are some key parameters that must be quantified, including:

- Traffic volume;
- Proportion of heavy vehicles;
- Types of heavy vehicles;
- Vehicle and axle weights;
- Prediction of vehicle and axle weight growth over time; and
- Prediction of traffic volume growth over time

The first challenge is to characterize what is currently on the roadway, and there are various tools that can be used to collect this information. For example, tube counters or automatic traffic recorders (ATRs) may be used to determine traffic volume and the proportion and types of heavy vehicles. Weight data are obtained at static weigh stations in addition to the occasional weigh-in-motion (WIM) system. Figures 1 and 2 illustrate some representative data pertaining to roads in Minnesota. Figure 1 shows the types of heavy vehicles on county roads while Figure 2 illustrates the weight distribution from a WIM on I-94 in Minnesota. These data, combined with traffic volume, collectively give a picture of the current traffic conditions and can be manipulated into ESALs or used as load spectra, as discussed later in this article.

The second, and more difficult, challenge is to predict how traffic will change over time and incorporate the predicted changes in design. Designing a pavement for more than 20 years means that there will be plenty of opportunity for new industries to develop along the route, changes in legal load limits, population growth, and any number of other factors that will change the traffic characteristics. Inaccurate predictions can mean early pavement failures because it was designed too thin or poor use of resources because it was designed too thick. Current means of making predictions include statistically based growth models built on historical trends. However, the principle from the financial world applies here as well, "Past performance is no indication of future performance," and can often render predictions inaccurate. Another method of predicting the future is to simply agree that traffic demands are increasing, not decreasing, and that some reasonable level of growth needs to be accounted for in design.

Figure 1. Average Vehicle Type Distribution on Minnesota County Roads *(1)*



Once the traffic data have been collected and the predictions made, they then need to be put into a form that is useful for the design method. For most empirically based methods, the traffic is systematically converted into ESALs so that one number may be used in design. M-E methods, however, utilize load spectra as will be discussed below. Regardless of the form, the resulting traffic characterization will only be as accurate as the input information so it is critical that an accurate depiction of traffic conditions be made.

The primary difference between how traffic is handled in empirically based methods versus M-E methods is illustrated in Figure 3. The figure illustrates the same traffic composition. ESALs rely upon empirical equivalence factors to convert the mixed traffic, representing many types of vehicles into one number for design. Load spectra, however, consider each type of load individually and model the pavement's response. Thus, load spectra are able to account for different tire pressures, axle configurations, etc. The pavement response is then used to predict the number of load repetitions that the pavement can withstand and the traffic volume is used to determine if there is sufficient capacity (number of allowable loads) designed into the pavement to withstand the applied traffic. Both ESALs and load spectra will be described in greater detail below.

ESALs

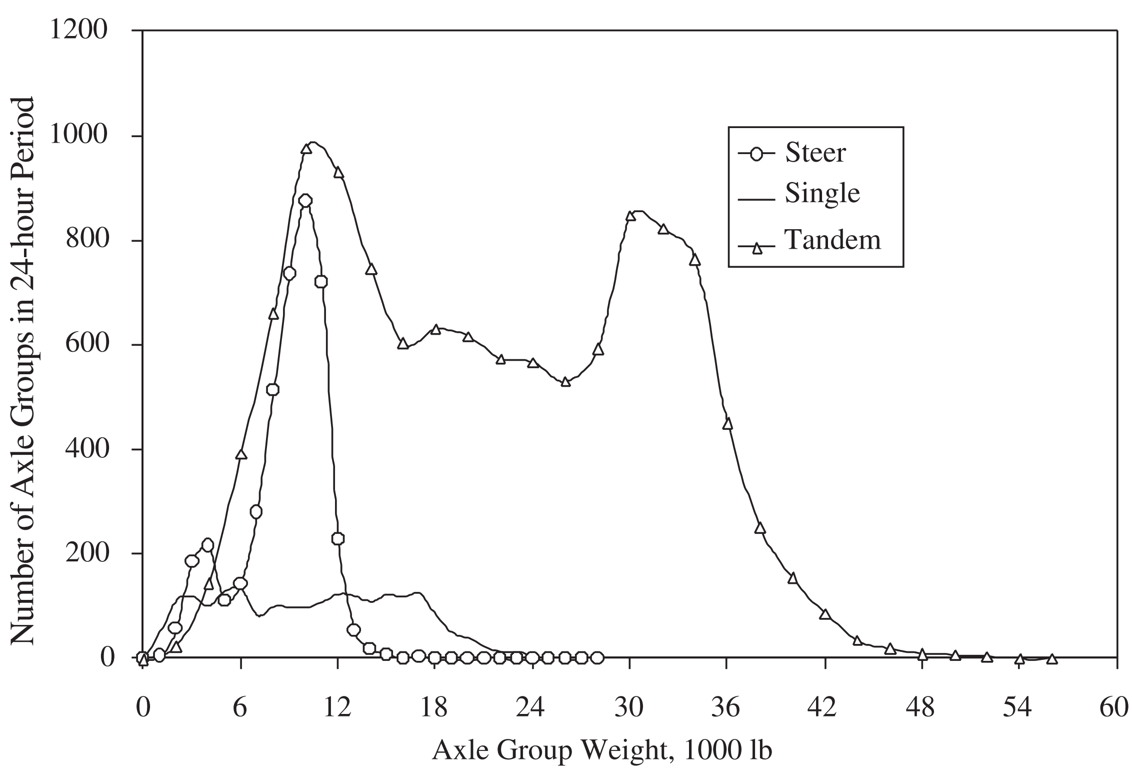
When using empirically based design methods, it is necessary to convert the number of axles and their weights into the total number of ESALs. An ESAL represents how much damage is done to a pavement per pass of a standard 18,000-lb. single axle with dual tires. All other expected axles or vehicles are then converted into equivalent single axle loads and the total number are then summed over the life of the pavement to determine the design ESALs.

Critical to computing ESALs are the empirically based load equivalency factors (LEFs) or truck factors. LEFs express the relative damage of any axle configuration and weight to the standard 18,000-

lb. single axle with dual tires. It's been found at numerous road tests that the LEFs are dependent on the type of pavement (flexible or rigid), structural thickness, type of axle grouping, and axle weight. Of these, the most important is axle weight since it has a dramatic effect on pavement damage. For example, doubling the axle weight from 18,000 lb. to 36,000 lb. on a single axle has the effect of causing anywhere between 15 to 24 times more damage.

For most traffic analyses, the process of determining ESALs occurs in two parts. The first is to determine the truck damage factors for each vehicle type in the traffic stream. Many agencies have performed traffic studies and determined an average damage factor for use in pavement design. These analyses are based upon gathering weight data and converting the various axle types and weights for the particular vehicle into ESALs and taking an average to represent the relative damage of the vehicle. For example, Table 1 lists the damage factors for the vehicles depicted in Figure 1. According to the table, one pass of a 5-axle truck is equal to about 1,600 passes of a passenger car, which provides justification for many agencies focusing upon characterizing heavy vehicles only.

Figure 2. Axle Group Weight Data from Mn/ROAD (2)



Where to begin...

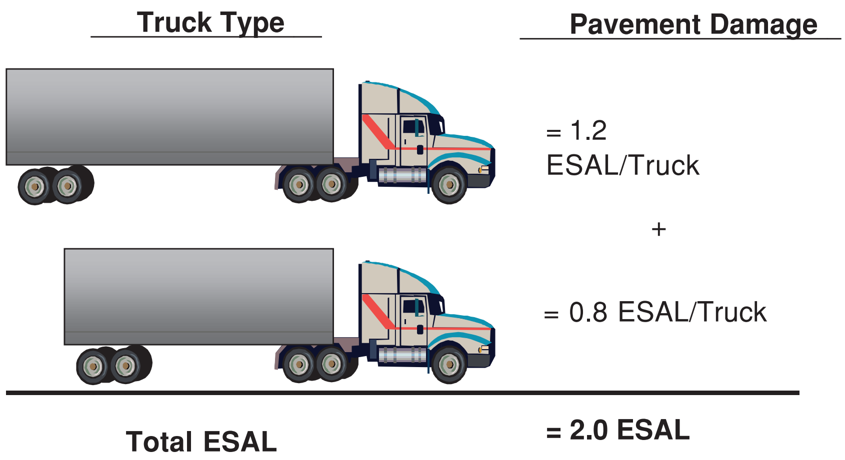
Once the necessary traffic information is gathered for a particular project, it can be worked into a form usable for design. However, many people are faced with the challenge of simply not knowing where to obtain traffic data.

The first step is to obtain traffic volume. Most state departments of transportation maintain traffic flow maps indicating traffic volume on major routes including interstates, state highways, and county roads. For smaller projects, many municipalities perform some traffic counts, and volume data may be available through the city engineer's office. Depending on the size and estimated cost of the project, it may be worthwhile to perform a special volume study to obtain an accurate traffic volume estimate.

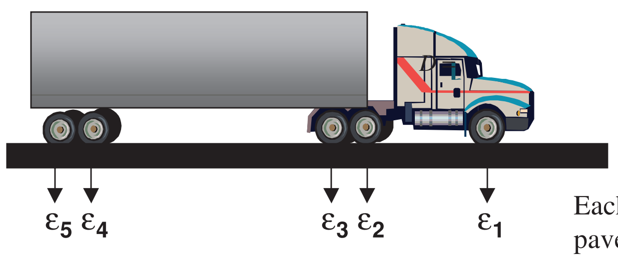
The second step is to determine the types of vehicles that comprise the traffic stream. This can be done by visually counting the types of vehicles over a given time period or using sensing systems that can determine vehicle types. A good source of this information is the local state department of transportation. Many states have conducted vehicle type surveys and may be able to recommend a typical vehicle type distribution for a particular road classification. Additionally, many design manuals, such as the Asphalt Institute's flexible pavement design guide (MS-1), contain default tables that can be used to determine the vehicle type distribution.

The last step is to determine either load equivalency factors (LEFs) if ESALs are the basis for design or axle weight data if using load spectra. Barring a special study to determine weights or damage factors for the particular project, many design manuals will contain default LEFs for particular vehicles. Load spectra may be a bit more difficult to obtain, but remember that the default LEFs must have been based on some weight data, and contacting the governing agency should enable you to obtain some weight data. As M-E methods become more prevalent, default load spectra should become more available.

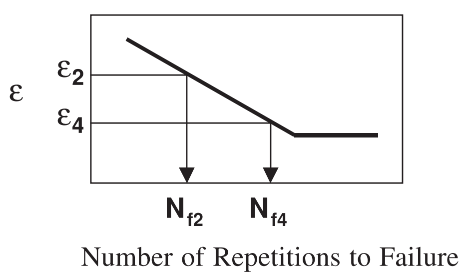
Figure 3. How Traffic Information is Used in Pavement Design



Equivalent single axle loads are calculated to reflect the pavement damage expected.



Each axle causes a repetition of pavement reaction (strain).



The pavement can tolerate a certain number of repetitions at each strain level before failure. (Only ε_2 and ε_4 shown.)

$$D = \frac{n_1}{N_{f1}} + \frac{n_2}{N_{f2}} + \frac{n_3}{N_{f3}} + \frac{n_4}{N_{f4}} + \frac{n_5}{N_{f5}}$$

The expected number of repetitions of each load (n_x) during the pavement life is divided by the number of repetitions to failure to determine the pavement damage (D).

In mechanistic design, pavement reactions to loads are related to pavement damage.

The second step of the process is to use the truck damage factors, such as those in Table 1, along with vehicle classification data (e.g., Figure 1) to sum the total number of ESALs over the expected life of the pavement. To accomplish this, traffic volume and growth information are also needed to account for how traffic may grow or change with time as discussed above.

The primary advantage of using ESALs is that one number is used for design, which simplifies the design process. However, ESALs are mostly empirical and the factors used in calculation depend on a specific set of conditions that include tire type, tire inflation pressure, axle spacing, axle load, type of pavement, thickness of pavement, and environment. Because of this, it is difficult to calculate ESALs for new types of vehicles or axles. For example, some trucks are now running "Super-Single" tires that are inflated to 150 psi rather than dual tires inflated to 100 psi. This type of tire has a much different effect on the pavement but cannot be accounted for directly in design because there is not an equivalency factor for this extreme high pressure. This example is one of the many reasons for moving toward M-E design and utilizing load spectra as will be discussed below.

Load Spectra

The use of load spectra are being encouraged for use in M-E design because they take full advantage of the ability to compute pavement response such as stress under specific loading conditions. For example, the pavement's response to a 50,000-lb. tridem axle with 110-psi tires can be calculated and then used to predict how many repetitions of that type of load the pavement can withstand before failure. In this way, many different types of loading conditions can be accommodated without relying on equivalency factors and having the results subject to their limitations.

So what are load spectra? They are the statistical distributions of axle weights, by axle type, that comprise a traffic stream. Put simply, they describe the many types of loads that a pavement experiences. One example of load spectra is depicted in Figure 2, which shows three different types of axle groups and their distribution of weights. The tandem axles in Figure 2 appear to be grouped around 8,000 lb. and 32,000 lb., which likely represent unloaded versus loaded trucks, respectively. The steer axles are grouped around 9,000 lb., which likely depict the average engine and cab weight for heavy vehicles.

In some instances, it may be difficult to obtain specific axle type and weight data such as pictured in Figure 2 for a particular project. However, it is feasible to develop likely load spectra for vehicle types, using weigh station or WIM data, in a particular region and use those as a reasonable estimate of the load types on the pavement and adjusting the results for the traffic volume.

It is important to realize that load spectra and ESALs come from the same information. In fact, load spectra are first used to find ESALs for a particular design by characterizing the axle weights for a particular type of vehicle. However, load spectra do not rely on equivalency factors and represent the true distribution of traffic weights expected on the pavement.

The primary problem with using load spectra is the same as using ESALs. Namely, the ability to forecast what the traffic will look like over a 20- to 30-year period. This problem is a difficult one to solve and will not be eliminated by using load spectra instead of ESALs. Only the careful consideration of current and historical traffic trends and the application of engineering judgment will enable the accurate prediction of traffic growth. However, using load spectra does eliminate some empiricism from the design process

Table 1. ESAL Truck Factors by Vehicle Type on Minnesota County Roads (1)

Vehicle Type	FlexiblePavement Truck Factors
Cars and Pickups	0.0007
2 Axle, 6 Tire - Single Unit	0.25
3+ Axle - Single Unit	0.58
3 Axle Semi	0.39
4 Axle Semi	0.51
5+ Axle Semi	1.13
Bus/Truck Trailers	0.57
Twin Trailers	2.40

without requiring additional data collection and takes full advantage of our ability to compute pavement response under load.

What the Future Holds

What's in the future? If we knew, we wouldn't be writing articles for trade magazines! However, there are some things that we need to keep in mind. Tire technology continues to improve, and with this improvement come implications for pavement designers. The use of smaller "high cube" tires on trailers allows more room for cargo, and these tires have significantly greater tire pressures. Super-single tires allow one tire to replace two tires on a dual wheel, and this reduces the number of tires that have to be replaced as well as reduces the rolling resistance and improving truck fuel mileage. Tire replacement is the highest maintenance cost associated with trucking. There is talk of designating dedicated truck corridors, which could drastically change truck traffic on certain routes. It is possible that more rail heads will be closed in the future, which would result in even a greater shift of freight from railroads to highways. The use of load spectra in the M-E design process will allow pavement designers to more easily analyze the impact of changes in future traffic on the road infrastructure.

This article focused on one piece of the design puzzle—traffic characterization. The primary change in traffic analysis when using M-E design is the elimination of the load equivalency factors and calculation of ESALs. Instead, weight distributions, called load spectra, will be worked with directly. The next article will highlight performance characterization in M-E design, focusing on the prediction of alligator cracking, rutting, and cold-temperature cracking. *HMAT*

References

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3. Timm, D.H., Newcomb, D.E., Birgisson, B. and Galambos, T.V., "Incorporation of Reliability into the Minnesota Mechanistic-Empirical Pavement Design Method," Report No. MN/RC – 1999 – 35, Minnesota Department of Transportation, 1999.

Dr. David E. Newcomb is NAPA's Vice President of Research and Technology. His e-mail address is dnewcomb@hotmix.org. Dr. David H. Timm is an Assistant Professor at Auburn University