Public Works Department

Memo

To: Chuck Soules
From: Tammy Bennett
Date: August 2, 2005
Re: Truck routes and pavement condition

You asked me to do some preliminary research documenting the effects of overweight vehicles on pavement conditions. There is a significant amount of information available on the subject. A sampling is attached for your review.

The research tends to focus on the extent of pavement damage or deterioration under given axle loads and axle configurations. The standard bearer has been the American Association of State Highway Officials (AASHO) Road tests of the late 1950s and early 1960. That research developed the equivalent single axle load (ESAL) factor relating the pavement stress imposed by an axle of any given weight to that imposed by a 18,000 pound single axle.

> This research indicated that, on average, pavement wear increases at approximately the fourth power of increases in axle weight. Doubling the weight of an axel, in other words, results in approximately 16-fold (i.e., 2x2x2x2) increase in the amount of stress applied to pavements. The AASHO Road Test research and resulting ESAL factors were also the basis for the oft-quoted statement that it takes 9,600 automobiles to do the same pavement damage as one fully-loaded, 80,000 pound, five-axle truck. [Oregon Department of Transportation, Policy Section, Policy Notes, June 2003]

The reported ratio of number of standard automobiles to do the same pavement damage as one fully loaded truck is variable by studies or sources. One document reports that on a flexible pavement, one truck does the same damage as up to 14,000 cars [City of Oxnard, CA, Fact Sheet, updated April 2004]. Other research shows the exponent relating pavement damage to increases in axle weight is closer to 2.5 than 4, but combined with other factors "the overall responsibility of trucks and other heavy vehicles for pavement costs [is] relatively unchanged" [Oregon Department of Transportation, Policy Section, Policy Notes, June 2003].

Attached you will find a variety of information on the topic. This was, by no means, an exhaustive or comprehensive search. I understood your original question to be whether there is scientific information available demonstrating a causal relationship between large truck traffic (e.g., axle loads) and pavement deterioration. The short answer to that question is yes.

Please advise if additional research would be helpful.

PAVEMENT Deterioration & Maintenance

Asphalt Deterioration

Asphalt deteriorates from two processes: **fatigue** and **aging**. Each deterioration process has its own set of pavement distresses (defects) that are caused by the process. Asphalt is also damaged from construction activities such as replacing utility lines or making utility connections for new users. These types of damage are referred to as utility cuts.

Fatigue

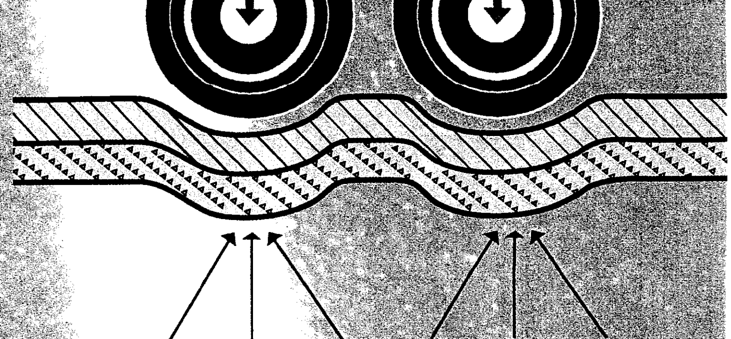
Fatigue results from heavy axle loads. (Figure 1) As the asphalt bends from heavy wheel loads, its ability to flex is consumed. This is much like what happens when you bend a paperclip back and forth. You can only bend it so many times until it breaks. With sufficient bending, the pavement begins to crack at the bottom. The failure at the bottom of the pavement structure will affect all layers. This manifests at the surface as alligator cracking, rutting, or sags. Shoving is another fatigue related distress that occurs generally only in the top layer. Fatigue failures are best repaired by removal and replacement of the asphalt in the affected areas. These repairs are commonly called digouts. Generally, when the area of digouts reaches approximately 10 percent of the total area of the street, the pavement is considered to have reached its useful life and requires major repair. Most fatigue damage results from heavy trucks and buses. One truck does the same damage as up to 14,000 cars.

Aging

The main element of the pavement section that ages is the asphalt concrete layer. Asphalt concrete (AC) is composed of aggregates (sand and gravel) and asphalt cement (a binder made of petroleum and/or synthetic materials). As the asphalt binder ages, it shrinks due to loss of it's volatile components. As the asphalt shrinks, the pavement will progressively crack from the resulting tensile stress in the layer. These cracks widen and increase over time until the pavement has a large checkerboard appearance. The aging process also causes the pavement to become more stiff* (brittle). The increased stiffness results in additional cracking from loaded vehicles. This load induced cracking from the brittleness of the asphalt concrete is very similar to fatigue cracking in appearance. Oxidation (from the oxygen carried by water) is the major cause of deterioration of the asphalt concrete binder. Water enters the pavement either from the surface through cracks or as water vapor from underneath. Thus, standing water on an asphalt surface can shorten the life of the surface significantly. This is why gutters are made of concrete, a material that is not as affected by water.

** Stiff, hard and brittle are sometimes used interchangeably*

Figure 1
Axel load on a flexible pavement. One truck does the same damage as up to 14,000 cars.



policy

June 2003

New Research on Pavement Damage Factors

Numerous factors contribute to deterioration of pavements and the consequent need to reconstruct, rehabilitate, or repair these pavements. These include environmental (weather) influences, dynamic interactions between pavements and vehicle speeds, numbers of tires per axle, tire pressures and suspension characteristics, and the frequency, spacing and magnitude of axle loads. Sub-base soil and terrain characteristics, as well as maintenance practices and the structure, materials, depth and construction quality of the initial pavement also play a role in determining pavement life.

The available research indicates that of these factors, by far the most important are the frequency, spacing and magnitude of axle loads. These are therefore the primary factors, along with environmental influences, considered in assessing responsibility for pavement deterioration.

Over the years, various sets of equivalence factors have been developed to compare the pavement stress imposed by different types and weights of vehicles. This article briefly compares the load-related damage factors from previous research with those from the new National Pavement Cost Model (NAPCOM) research.

Previous Research

The pavement damage equivalence factors used in highway cost allocation, truck size and weight, and other pavement studies prior to the mid-1990s were based on the results of the American Association of State Highway Officials (AASHO) Road Test of the late 1950s and early 1960s. The results of this research were used to develop equivalent single axle load (ESAL) factors relating the pavement stress imposed by an axle of any given weight to that imposed by an 18,000-pound single axle. This weight was selected as the benchmark axle weight because it was the maximum legal weight of a single (dual-tired) axle at the time of the AASHO Road Test.

This research indicated that, on average, pavement wear increases at approximately the fourth power of increases in axle weight. Doubling the weight on an axle, in other words, results in an approximately 16-fold (i.e., two to the fourth power, or 2x2x2x2) increase in the amount of stress applied to pavements. The AASHO Road Test research and resulting ESAL factors were also the basis for the often-quoted statement that it takes 9,600 automobiles to do the same pavement damage as one fully-loaded, 80,000-pound, five-axle truck.

New Research

For highway cost allocation studies (HCASs), the older AASHO Road Test results have now been replaced by those from the newer NAPCOM research. NAPCOM is a complex simulation model developed by the Federal Highway Administration in 1992 that further refines the deterioration-based method employed in the 1982 Federal HCAS. It uses information on specific, representative highway sections supplied by the states through the Highway Performance Monitoring System. NAPCOM models eleven different pavement

This issue of Policy Notes was written by John Merriss, Policy Section Manager, ODOT Policy Section, and does not necessarily reflect the views of the Oregon Department of Transportation or the Policy Section. Author can be reached by email at John.S.Merriss@odot.state.or.us or call (503) 986-3474.

Oregon Department of Transportation, Policy Section
John Merriss, Policy Section Manager
555 13th Street NE, Suite 2, Salem, Oregon 97301-4178
(503) 986-3466

distresses such as faulting, fatigue cracking, thermal cracking, rutting and loss of skid resistance to estimate when pavement restoration will be required and determine expected pavement condition at the end of each year of the analysis.

The NAPCOM results and load equivalence factors (LEFs) developed from these results have been used in the 1997 Federal HCAS and the most recent national Truck Size and Weight Study, as well as the 1999, 2001, and 2003 Oregon HCASs. The NAPCOM results differ from those of the older AASHO Road Test research in two major ways:

1. Unlike the approximately fourth-power relationship established by the earlier research, NAPCOM estimates separate pavement wear relationships for each different distress modeled. For most, the exponent is considerably less than four. While the precise relationship differs depending on the type of pavement and distress being considered, the NAPCOM research suggests, on average, the exponent relating pavement deterioration to increases in axle weight is closer to 2.5 than 4. This means a doubling of axle weight results in an approximately 6-fold, rather than 16-fold, increase in load-related pavement damage.

   As with the older ESAL factors, separate LEFs have been developed for rigid (Portland cement concrete) and flexible (asphaltic concrete) pavements. Using a weighted average reflecting the overall mix of Oregon pavement types (about 93% flexible and 7% rigid) suggests it takes roughly 750 automobiles weighing 3,800 pounds each to do the same pavement damage as one fully-loaded, 80,000-pound truck. This is substantially lower than the 8,000-10,000 to one relationship derived from the older ESAL factors.

2. The second major finding of the NAPCOM research, which has received less attention than the first, is that weather and other non-load-related factors play significantly less of a role in pavement deterioration than suggested by the earlier research. This largely offsets the impact of the lower exponential relationship between pavement wear and axle weight, so that the overall responsibility of trucks and other heavy vehicles for pavement costs is approximately the same as under the older research.

   Use of the newer LEFs instead of the older ESAL factors in a HCAS, in other words, results in a shift of responsibility for pavement costs within the heavy vehicle classes, specifically from the heavier axle weight classes to the lighter and medium-weight axle classes, but does not materially change the overall responsibility of heavy vehicles for pavement costs. This is illustrated by the fact the 2003 Oregon HCAS found heavy vehicles, as a group, to be responsible for approximately 70% of pavement reconstruction and rehabilitation costs, a result generally similar to those of the past several Oregon studies.

Summary

New research on the relationship between vehicle weight and pavement deterioration finds this relationship to be less extreme than previously thought. This research suggests that, on average, the exponent relating pavement damage to increases in axle weight is closer to 2.5 than 4. At the same time, this research indicates weather and other non-load-related factors play less of a role in pavement deterioration than suggested by the earlier research. The combined effect of these two findings is to leave the overall responsibility of trucks and other heavy vehicles for pavement costs relatively unchanged, but to shift more of this responsibility from heavier axle weight vehicles to lighter and medium-weight axle vehicles. These findings have been reflected in the results of the 1997 Federal HCAS and the past three Oregon HCASs.

Loads

Loads are the vehicle forces exerted on the pavement (e.g., by trucks, heavy machinery, airplanes). Since one of the primary functions of a pavement is load distribution, pavement design must account for expected lifetime traffic loading. Loads can be characterized by tire loads, axle and tire configurations, load repetition, traffic distribution across the pavement and vehicle speed.

Figure 1: H-1 During Rush Hour

Figure 2: Buses at Ala Moana

Load Characterization

- *Tire Loads*. Tire loads are the fundamental loads at the actual tire-pavement contact points.
- *Axle and tire configurations*. While the tire contact pressure and area is of concern, the number of contact points per vehicle and their spacing is critical. As tire loads get closer together their influence areas on the pavement begin to overlap, at which point the design characteristic of concern is no longer the single isolated tire load but rather the combined effect of all the interacting tire loads.
- *Load repetition*. Loads, along with the environment, damage pavement over time. The standard model asserts that each individual load inflicts a certain amount of unrecoverable damage. This damage is cumulative over the life of the pavement and when it reaches some maximum value the pavement is considered to have reached the end of its useful service life.
- *Traffic distribution*. On any given road, one direction may carry more loads than the other. Furthermore, within this one direction, each lane may carry a different portion of the loading. The outer most lane often carries the most trucks and therefore is usually subjected to the heaviest loading.
- *Vehicle speed*. In general, slower speeds and stop conditions allow a particular load to be applied to a given pavement area for a longer period of time resulting in greater damage. If mix design or structural design have been inadequate, this behavior is sometimes evident at bus stops (where heavy buses stop

and sit while loading/unloading passengers) and intersection approaches (where traffic stops and waits to pass through the intersection).

Load Quantification

Pavement structural design requires a quantification of all expected loads a pavement will encounter over its design life. This quantification can be done in several ways:

- *Equivalent single axle loads (ESALs)*. This approach converts wheel loads of various magnitudes and repetitions ("mixed traffic") to an equivalent number of "standard" or "equivalent" loads based on the amount of damage they do to the pavement. The commonly used standard load is the 18,000 lb. equivalent single axle load. Using the ESAL method, all loads (including multi-axle loads) are converted to an equivalent number of 18,000 lb. single axle loads, which is then used for design. A "load equivalency factor" represents the equivalent number of ESALs for the given weight-axle combination. As a rule-of-thumb, the load equivalency of a particular load (and also the pavement damage imparted by a particular load) is roughly related to the load by a power of four (for reasonably strong pavement surfaces). For example, a 36,000 lb. single axle load will cause about 16 times the damage as an 18,000 lb. single axle load. Table 1 shows some typical load equivalencies (note that spreading a load out over two closely spaced axles reduces the number of ESALs). Figure 3, using some approximations, shows some general vehicle load equivalencies - note that buses tend have high load equivalency factors because although they may be lighter than a loaded 18-wheeler, they only have two or three axles instead of five.

Load	Number of ESALs
18,000 lb. single axle	1.000
2,000 lb. single axle	0.0003
30,000 lb. single axle	7.9
18,000 lb. tandem axle	0.109
40,000 lb. tandem axle	2.06

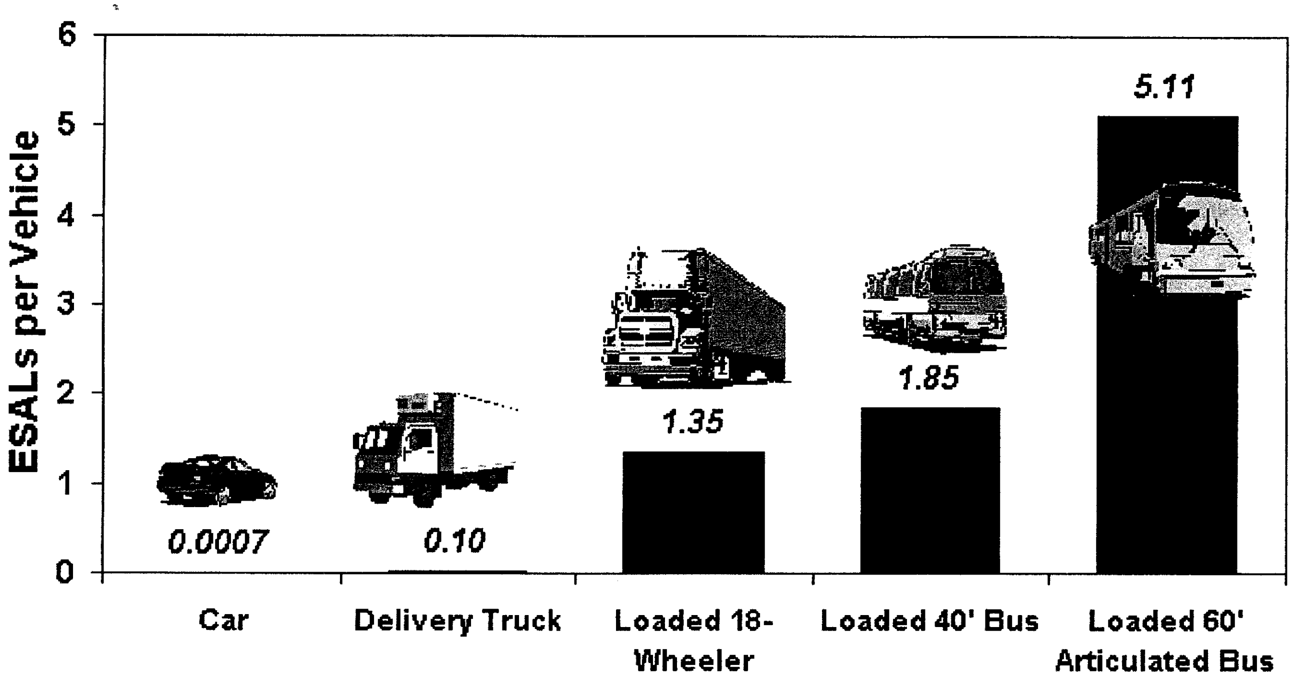


Figure 3: Some Typical Load Equivalency Factors

- *Traffic Index* (TI). The traffic index is associated with the California method of pavement structural design. Essentially, it has evolved in to a way of expressing ESALs as a single number or index (see Figure 4).

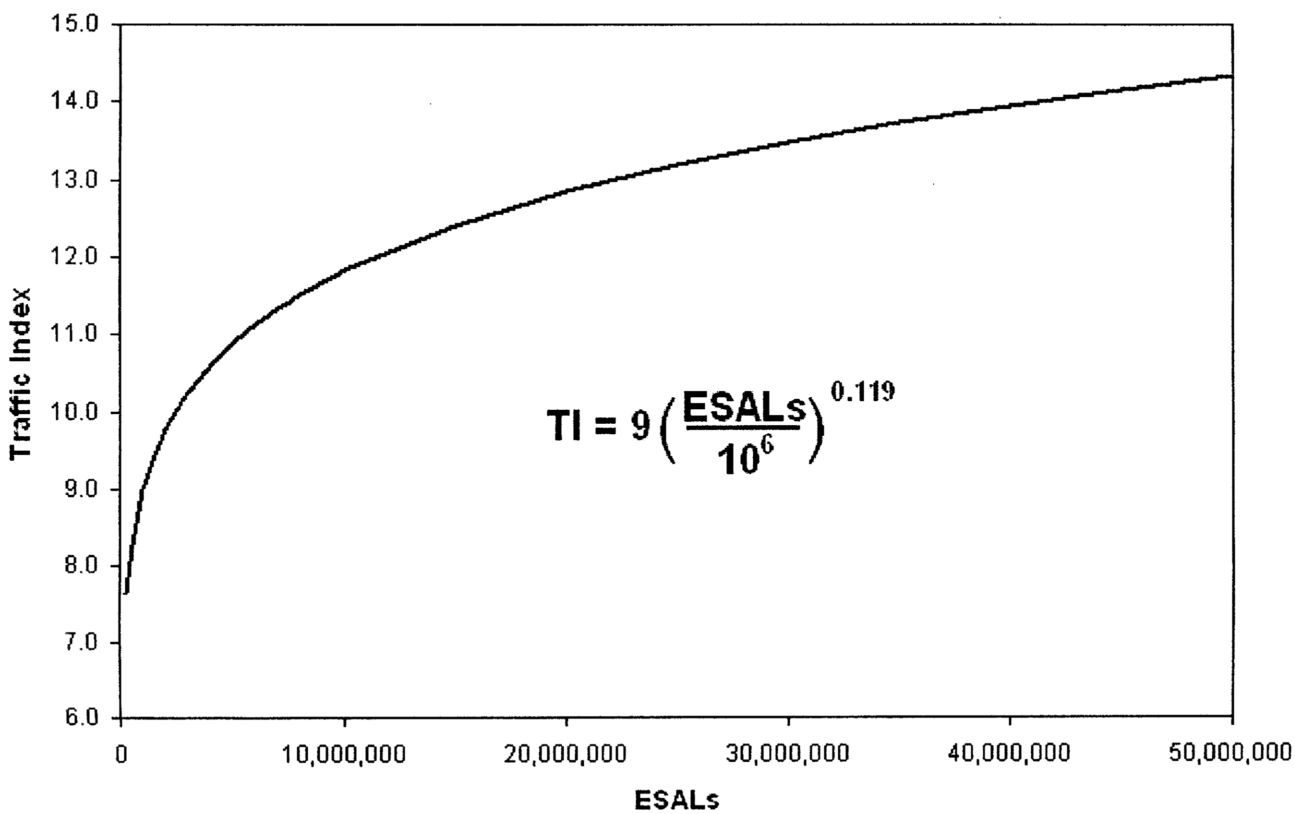


Figure 4: Traffic Index vs. ESALs

- *Load spectra*. This approach characterizes loads directly by number of axles, configuration and weight. It does not involve conversion to equivalent values. Structural design calculations using load spectra are generally more complex than those using a traffic index or ESALs because loading cannot be reduced to one equivalent number. Load spectra will be an option for use in the next AASHTO *Design Guide*.

All approaches use the same type and quality of data but the load spectra approach has the potential to be more accurate in its load characterization.

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

Project Summary Report 2123-S

Project 0-2123: Develop a Method for Determining Allowable Loads on Load-Zoned Pavements - Phase II

Author: Emmanuel G. Fernando

PROJECT SUMMARY REPORT

Methodology for Load-Zoning Pavements

Texas has approximately 17,500 miles of load-zoned pavements, comprising more than 20 percent of the number of centerline miles on the state-maintained system. These pavements are primarily low-volume farm-to-market roads constructed in the 1950s, at a time when legal load limits were lower than they are now. Like most governments, Texas does not have the money to upgrade all existing load-zoned pavements to accommodate present truck traffic, nor is this justifiable for many of these pavements because of the continuing low traffic volumes. To do so would divert funds from higher-priority highway and bridge improvement projects.

Most load-zoned roads in Texas are still posted with a gross vehicle weight (GVW) limit of 58,420 lb, corresponding to the legal load limit at the time these roads were designed and built. Since the load from a vehicle is transmitted to the pavement through its axles, establishing load limits based on axle weight and axle configuration is a more rational approach than the one presently used. Recognizing the need for a better methodology of load-zoning pavements, the Texas Department of Transportation (TxDOT) funded a project to develop a procedure for evaluating load restrictions on the basis of axle load and axle configuration. Research efforts conducted at the Texas Transportation Institute (TTI) led to the development of the Program for Load-Zoning Analysis (PLZA) that pavement engineers may use to evaluate the need for load restrictions and to determine, as appropriate, the single and tandem axle load limits based on a user-prescribed reliability level.

What We Did...

A load-zoning analysis will generally address the following questions:

- Is there a need for posting load limits on a given route?
- If load restrictions are necessary, what axle load limits should be used?

Consequently, the framework researchers used to develop PLZA incorporates these two steps in the load-zoning analysis. This approach was adopted as most load-zoning evaluations in recent years pertained to the removal of existing load limits on roads that have been upgraded through rehabilitation or reconstruction. This situation has come about since the districts make every effort to rehabilitate an existing load-zoned road to a higher standard to accommodate truck traffic at the legal load limits. Thus, it is expected that most applications will relate to the applicability of removing existing load limits, rather than to posting new load limits.

The methodology developed for evaluating load restrictions is based on predicting the effects of load limits on pavement performance. Figure 1 illustrates the framework used to develop the load-zoning analysis program. In this framework, axle weight restrictions are established based on the minimum service life or time to next resurfacing required by the pavement engineer. The evaluation of performance uses data from characterization of the route and from the determination of the expected number of truck loadings for the user-specified analysis period.

To predict the induced pavement response under surface wheel loads, PLZA uses a layered elastic pavement model that permits users to characterize pavement materials as linear or nonlinear. The predicted horizontal strain at the bottom of the asphalt layer and the vertical strain at the top of the subgrade are used with the Asphalt Institute performance equations to predict the number of allowable load repetitions for given axle loads and configurations. Due to variability in materials and layer thicknesses, predictions of pavement life will vary accordingly along the route. To consider this variability, PLZA uses the service life predictions to compute the probability that the service life will be less than the required life specified by the engineer. The reliability is, thus, determined and used in PLZA to establish the need for load restrictions and to determine single and tandem axle load limits, as appropriate.

What We Found...

Sensitivity Analysis of Predicted Performance

Researchers conducted a sensitivity analysis of predicted pavement life to:

- evaluate the effects of pavement design factors on predicted performance;
- identify design variables that are important in the load-zoning analysis; and
- verify whether the effects of design variables are consistent with engineering experience and practice.

The findings from the sensitivity analysis are summarized as follows:

- Overall, the results showed that pavement life (based on the Asphalt Institute fatigue equation) is influenced the most by surface thickness and base modulus, and, to a lesser degree, by the base thickness and surface modulus. The subgrade modulus exhibited an appreciable effect only for the thin pavement.
- On the basis of rutting, the analysis showed that predicted pavement life is influenced significantly by the layer moduli and thicknesses. In particular, the surface thickness, base thickness, and subgrade modulus are observed to have the most impact on the predicted life, which varied in the same direction as the change in each design variable.

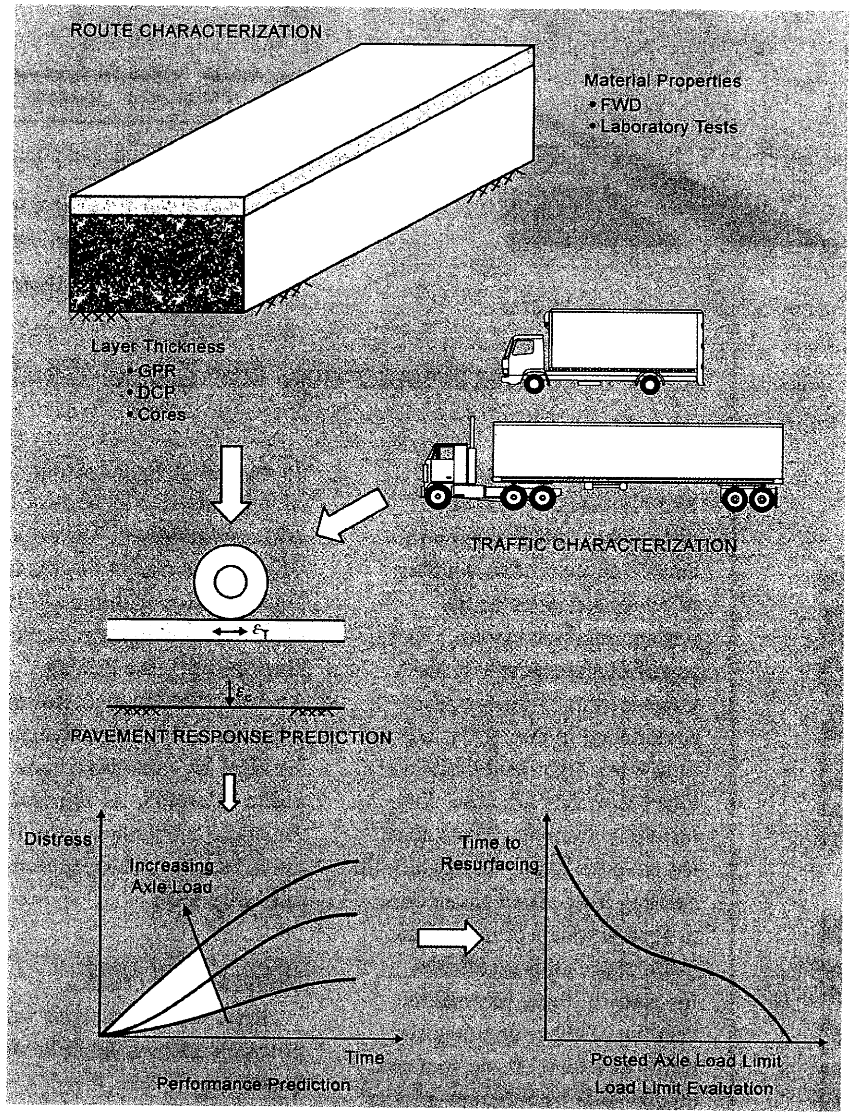


Figure 1. Methodology for Load-Zoning Pavements

- The rut depth criterion was observed to govern the predicted pavement life for the thin and medium pavements, while the fatigue criterion governs the service life for the thick pavement. Since most roads that undergo a load-zoning analysis fall under the thin and medium categories, this observation implies that, for roads comparable to the pavements analyzed, rutting will likely control the load restrictions, based on the Asphalt Institute performance equations.
- In terms of options to rehabilitate existing load-zoned roads to carry legal load limits, the results from the sensitivity analysis imply that increasing the surface thickness and/ or improving the base material are primary options an engineer should consider to improve the expected fatigue life of the pavement. The effect of these changes on predicted pavement response is to reduce the bending effect under load, and the tensile strain at the bottom of the surface mix. Theoretically, this reduction in tensile strain translates to a higher number of load repetitions prior to crack initiation. In addition, the increase in surface thickness adds to the number of load repetitions for crack propagation. On the basis of the rut depth criterion, the primary options

For More Details . . .

The research is documented in Report 2123-2, *Development of an Analysis Procedure for Load-Zoning Pavements.* In addition, detailed instructions on using the PLZA analysis software are found in Report 2123-1, *Program for Load-Zoning Analysis (PLZA): User's Guide.*

Research Supervisor: Emmanuel G. Fernando, e-fernando@tamu.edu, (979) 845–3641

Key Researcher: Wenting Liu, w-liu@tamu.edu, (979) 845–5943

TxDOT Project Director: Joe Leidy, jleidy@dot.state.tx.us, (512) 465–3683

To obtain copies of reports, contact Dolores Hott, Texas Transportation Institute, Information & Technology Exchange Center, (979) 845-4853, or e-mail d-hott@tamu.edu. See our online catalog at http://tti.tamu.edu.

TxDOT Implementation Status
October 2003

The methodology for Load-Zoning Analysis has been implemented at the Pavement & Materials Systems branch of the Materials and Pavements Section of the Construction Division. This methodology and design software will be made available to the Districts in the future through a web-based training site. The web-based training is being developed under IPR 5-1869. TxDOT employees will have access to this training through a link in the Intranet that will also allow the down loading of the programs.

For more information, please contact: Dr. German Claros, P.E., Research and Technology Implementation Office (512) 467-3881 or gclaros@dot.state.tx.us.

YOUR INVOLVEMENT IS WELCOME!

Disclaimer

an engineer should consider are to increase the surface thickness and/or base thickness, and to improve the subgrade through stabilization or replacement with a better material. The effect of these changes is to reduce the compressive strain at the top of the subgrade, resulting in a predicted increase in pavement life.

Application of Load-Zoning Analysis Procedure

Researchers also used the load-zoning procedure to evaluate the need for load restrictions on four in-service pavements located in the Waco and Tyler Districts. This evaluation was conducted by using pavement evaluation techniques already implemented within TxDOT [specifically, the ground penetrating radar (GPR), falling weight deflectometer (FWD), dynamic cone penetrometer (DCP), COLORMAP, and MODULUS] and by using standard traffic information employed in pavement design. The experience with the initial applications of the load-zoning program demonstrated that it can be readily implemented within the department, in the researchers' opinion. Service life predictions from PLZA were also assessed against corresponding predictions from the MODULUS program. The results of this comparison showed that, in terms of the need for load restrictions, both programs produce the same ranking of the pavement sections tested and analyzed.

The Researchers Recommend...

Based on results from the pilot demonstration of the PLZA program, *researchers* recommend posting of load limits on the basis of axle load and axle configuration. The evaluation of axle load limits indicated that single and tandem axle configurations have different damaging effects on pavements, and that posting load limits in terms of axle weight may actually help TxDOT preserve the highway network in a way that will maintain or have the least negative impact on trucking productivity.

Researchers recommend that the load-zoning procedure be initially implemented through the Materials and Pavements Section of the Construction Division, which is staffed with engineers trained to operate GPR, FWD and DCP equipment, and to analyze GPR and FWD data using COLORMAP and MODULUS, respectively. As the need arises, implementation of the analysis program may be phased into the districts, particularly those with significant mileage of load-zoned pavements. The implementation of the program within the districts may be realized through training sessions conducted in-house or through an interagency agreement.

In actual applications, users must first characterize the route to be analyzed. This will require characterizing the truck traffic on the route, determining pavement layer thicknesses, and evaluating material properties. Truck traffic data may be requested from the Transportation Planning and Programming (TP&P) Division of TxDOT. The standard information reported by TP&P in the "Traffic Analysis for Highway Design" tables are used in PLZA to evaluate the need for load restrictions and to determine, as appropriate, the applicable single and tandem axle weight limits on a given route.

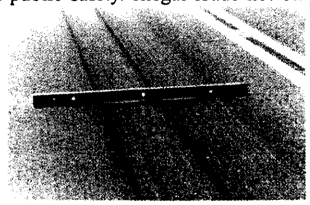
Researchers strongly suggest a GPR survey on the route to establish the variations in layer thicknesses. This survey should be conducted at the beginning of the evaluation. FWD data should be collected following the protocol established by TxDOT. For load-zoned pavements with surface thicknesses greater than 3 inches, pavement temperature measurements should be made to correct backcalculated asphalt concrete moduli to a standard temperature. Alternatively, infrared surface temperatures may be measured during the survey for the purpose of predicting pavement temperatures at the time of test using the Texas-LTPP equation implemented in the Modulus Temperature Correction Program. Use of this equation requires the previous day's maximum and minimum air temperatures, which are readily obtained from the local weather service.

The researchers recommend that the FWD data be stored in a separate file for each segment of the route surveyed. Each file is then analyzed with the MODULUS program to estimate the stiffness of each pavement layer. The output file of the backcalculated moduli for each segment is directly input to the PLZA program for the load-zoning analysis.

In view of the possible variations in layer thickness and materials along the route, different results may be obtained for the different segments delineated from the GPR data. In practice, it will be difficult to implement numerous postings on a given route. Thus, the pavement engineer must still use his or her judgment in taking the results of the load-zoning analysis to establish how a given route should be posted. For example, the engineer may make the decision to post the route based on the weakest segment. This decision should also consider the current truck use of the particular route, alternative roadways that may be taken, the presence of load-zoned bridges, and the need to upgrade the route to carry truck traffic at the legal load limits.

The Link to Highway Safety

Truck weight enforcement is not only a matter of economics, but also a matter of public safety. Illegal loads not only make roads



rougher, but also create deep ruts that can fill with rainwater or ice, making driving more dangerous for everyone.

Frequently Asked Questions

People occasionally ask whether weight restrictions could be relaxed without increasing road damage. Common questions are:

- Can trucks reduce speed rather than reduce load? This question often arises in the spring, when load restrictions are needed to protect pavements weakened by the spring thaw. Unfortunately, even though some local agencies still try to avoid load limits by reducing speed limits, this practice does not work. In fact, road damage increases significantly when heavy vehicles are driven more slowly.
- *If a truck's gross weight is legal, why do axle weights matter?* This question is sometimes raised by persons cited for overweight axle or axle group violations, even though the total (gross) weight of their vehicle did not exceed the legal limit. However, pavement damage from two axles—one light and one heavy—actually exceeds the damage from properly loaded axles. The extra damage created by the overloaded axle exceeds the reduced damage created by the lighter one.
- *If agricultural vehicles with low-inflation tires can safely carry heavy loads in fields, why can't they operate loaded on highways?* Even though vehicles like chemical applicators and grain carts can transport very heavy loads in fields, they seriously damage gravel and paved roadways when loaded beyond legal limits. The roadway surface is damaged because the vehicles' lugged tires concentrate the load into small contact areas. The pavement's underlying layers fail because they cannot withstand the total load imposed upon them. These loads also pose a serious problem for bridges, especially on county and township roads.

The trucking industry will always be an integral mode of transportation for the City of Sioux Falls. Without trucking, every facet of our economy would suffer. Therefore, we must continue to do everything possible to achieve the greatest benefit from our investment in the transportation system. A primary way of ensuring our state highways and local roads do

The Need for Responsible Hauling

State and local governments' responsibility to provide mobility and safety cannot be accomplished if illegally loaded vehicles prematurely consume the life of roads and bridges. Providing a system that is economical, comfortable, and safe depends not only on the government's investment of time, effort, and money, but also on the responsible behavior of highway users.

The vast majority of haulers in South Dakota do operate legally. Of the nearly 600,000 vehicles weighed each year, only about 3,000—one half of one percent—are cited for overweight violations. Of those cited, only about 600 are severely enough overweight to be assessed civil penalties exceeding $100.

While a small number of haulers knowingly operate illegally, their disregard for weight limits creates costly damage that other, responsible taxpayers must pay for. Controlling the irresponsible behavior of these intentional violators is impossible without effective enforcement and prosecution.

Recent efforts to control illegally overweight vehicles have clearly begun to reduce the rate of grossly overweight loads. In 2000, 8.6% of overweight vehicle citations were for loads more than 10,000 pounds over the legal limit. The rate decreased to 6.0% in 2001, and 5.9% in 2002. Overall, the incidence of grossly overweight loads has dropped by nearly a third since more stringent penalties and enforcement were enacted.

Relaxing weight regulations and enforcement would erase the progress that has been made to protect the public investment in state and local roads. In the words of Ted Eggebraaten, Brookings County Highway Superintendent, "If we lose the control we have with the new overweight laws in place, it will only add to our problems with roads and bridges. Brookings County would not be able to keep up our road system maintenance if the control is taken away." The Department of Transportation also considers sound weight enforcement essential to its mission to "provide a transportation system to satisfy the diverse mobility needs" of travelers, shippers, and haulers in South Dakota. Especially in a time of limited funding, protecting the existing highways from unnecessary damage is clearly the wisest course of action.

SDDOT Briefing

Truck Weights and Highways

Illegally overweight vehicles damage South Dakota roads, shorten road life, and increase costs to both the trucking industry and taxpayers. During the past several years, the South Dakota Legislature has enacted laws to protect state and local highways from damage caused by illegally overweight vehicles:

- In 1996, the Legislature limited the maximum weight allowed on axles (other than steering axles) to 500 pounds times the total width, in inches, of all tires mounted on the axle. This action ensured that the weight carried on axles fitted with single tires (as opposed to conventional dual tires) would not exceed pavements' load capacity.
- When the Legislature raised the state fuel tax in 1999, it also increased civil penalties for overweight trucks to safeguard the public's investment. The graduated penalty schedule discourages intentional violations that most severely damage roads and bridges, but imposes more modest fines for lesser, unintentional overweights.

Pounds Overweight	Civil Penalty per Pound
1,000-3,000	$0.05
3,001-4,000	$0.15
4,001-5,000	$0.225
5,001-10,000	$0.375
> 10,000	$0.75

- To protect the public investment in local roads and bridges, the Legislature enacted a law requiring the Department of Transportation to monitor how diligently counties prosecute overweight violations and, if necessary, to withhold funding from counties that fail to act responsibly.

The South Dakota Department of Transportation supports all of these legislative actions, which have improved awareness and compliance with truck weight regulations. Fewer vehicles are operating seriously overweight, preventing needless damage to roads and bridges and saving taxpayers millions of dollars.

It is important for those responsible for funding, building, and maintaining highways to understand the reasons behind truck weight regulations and to be able to explain them when shippers, haulers, business contacts, and personal acquaintances inquire about them.

South Dakota Supports Trucking

South Dakota values the trucking industry and its contribution to the economy and well being of the state. Nearly everything we own, eat, use, grow, or manufacture is carried by truck on at least part of its journey.

Because of the importance of trucking, the South Dakota Legislature and other branches of state government have historically adopted rules and procedures that help the industry to operate competitively:

- To ease regulatory burdens, the Department of Revenue has joined the International Fuel Tax Agreement and the International Registration Plan. Both enable motor carriers to register in just South Dakota but operate in all states and provinces. Efforts are underway to provide online IRP and IFTA services to the trucking industry.
- Unlike most states, South Dakota does not impose absolute gross weight limits on trucks. Instead, it allows essentially unlimited gross weight, provided the load is supported by enough tires and axles to prevent road and bridge damage.
- South Dakota grants tolerances for hauling agricultural loads. Loads from field to farm are allowed to weigh 10% more than the normal weight limit, while loads from farm to market are allowed 5% more than normal.
- To help truckers comply with weight regulations, the Highway Patrol will, without charge, weigh vehicles and instruct haulers on proper loading.
- Together with the Department of Revenue and the Highway Patrol, the Department of Transportation has developed an automated permitting system that allows truckers to obtain permits online and quickly identifies safe routes for movement of oversize and overweight vehicles.
- To reduce delays and improve traffic safety, the Department of Transportation will replace the port of entry at North Sioux City with a new facility near Jefferson in 2003. Through use of in-motion weighing and vehicle transponders, the new port will allow truckers with good safety records and legal weights to bypass the port, saving valuable hours of operating time.

The Need to Be Legal

Why are truck weight regulations so important? It's really a matter of dollars and cents, because roads and bridges have to be designed, built, and maintained to carry heavy axle loads. The heavier the axle loads, the more expensive roads and bridges become. The costs listed in the following table show that constructing roads is very expensive; building them to carry large numbers of overweight vehicles would make them even more expensive.

Cost per Mile to Construct	
Interstate 4-lane highway—concrete	$1,900,000
State 2-lane highway—concrete	$941,000
State 2-lane highway—asphalt	$775,000
Secondary 2-lane highway—asphalt	$476,000
Thin asphalt overlay—24' wide	$112,000
Gravel base & surface—28' wide	$107,000

Every axle passing over a highway consumes a portion of the pavement's life. With each application of load, the pavement experiences compression and bending that eventually lead to rutting and cracking. Extensive road tests over the past fifty years have shown that the amount of pavement life consumed by heavy axles greatly exceeds the amount of life consumed by light axles.

Axle Weight (pounds)	Pavement Life Consumed†
2,000	0.001
10,000	0.06
18,000	0.66
20,000	1.00
22,000	1.46
24,000	2.07

† all loads compared to a legal 20,000-pound axle

Two important concepts are evident from this table:

- First, heavy axles consume much more pavement life than light axles. Even a legal 20,000-pound truck axle consumes a thousand times as much pavement life as a 2,000-pound automobile axle.
- Second, the amount of life consumed rises much faster than the axle weight. For a seemingly modest 10% increase in weight (from a legal 20,000-pound axle to an overweight 22,000-pound axle), the amount of consumed life soars by nearly 50%. A 20% overweight consumes more than twice as much pavement life as the legal load.

Damage to Bridges

Damage from illegally overweight loads is not confined to pavements. Bridges prematurely age, just as pavements do, when subjected to illegal loads. If the loads are great enough, they can actually destroy a structure.

An example from Tripp County is pictured, but it is not the only case. In the past two years alone, six county bridges had to be completely replaced because of damage from illegally overweight trucks:

- Two bridges in Moody County had to be replaced at a total cost of $692,000;
- Two Brookings County bridges were rebuilt at a total cost of $295,000;
- One Faulk County bridge had to be replaced at a cost of $125,000;
- The bridge in Tripp County was replaced with culverts at a cost of $18,000.

These illegally overweight loads not only cost counties more than $1.1 million, but also deprived other road users of convenient access to their homes and farms. In each case, the board of county commissioners had to declare an emergency and close the road until a new structure could be built.

As costly as these cases were, they represent only a portion of the bridge damage attributable to illegally overweight loads. Many other structures have certainly been damaged, but in ways that are not yet apparent.

TTI

Review Featured Research

Software will help preserve our country drives

Too many trucks carrying heavy loads can easily ruin anybody's Sunday drive in the country. The pavement on much of Texas' rural, low-volume, farm-to-market road simply can't hold up to the documented increases in today's truck traffic and load weights. Many were constructed in the 1950s when legal load limits were set based on a gross vehicle weight (GVW) restriction of 58,420 lbs. The Texas Department of Transportation (TxDOT) is aware of the need to adjust the posted load weight restrictions on certain roadways. However, the state has approximately 17,500 miles of load-zoned pavements that need to be monitored, evaluated, and possibly adjusted.

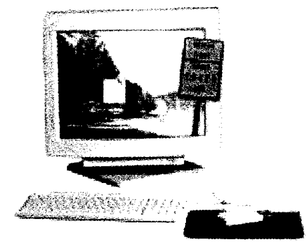
In addition, TxDOT now recognizes (and research has proven) that axle loads are actually more important in setting load limits than gross vehicle weight. The gross load from a vehicle is transmitted through the axle tires to the pavement, so a vehicle that is legally within the GVW may in fact still be damaging the roads due to high axle weight.

Since mass resurfacing of all the low-volume FM roadways to allow for higher load zoning is cost prohibitive, TxDOT is looking for different solutions. Texas Transportation Institute (TTI) Associate Research Engineer Emmanuel Fernando has developed a new software tool to help determine whether roadways need new load restrictions based on axle weight. The program will also determine single and tandem axle load limits as needed.

This new software program is currently being used by the Pavements Section of TxDOT--primarily to determine whether load limits can be removed from an existing route that has undergone recent rehabilitation. According to TxDOT, the districts typically request an evaluation of a given roadway and then assist the pavement section by collecting the necessary data to input into PLZA. Using information about the materials that make up the road, the anticipated traffic, and the desired design period, PLZA implements a methodology that evaluates the axle weight restrictions in view of GVW restrictions.

According to Fernando, another primary reason to use this design procedure is to help meet the desired design period. "That is, how long do you want this pavement to last once you do rehabilitation on it?" says Fernando. "The pavement may be able to withstand a single load application, but really we are talking about repetitive load application. It may be that for the given design period and for the given volume of traffic, you would reach your design life, say, in five years instead of 10 years."

This article is from the Texas Transportation Researcher, Volume 36, Number 3 (2000).



For more information:

Contact: Emmanuel Fernando

Phone: 979-845-3641

E-mail: e-fernando@tamu.edu

Publication:

TTI Report 2123-1, "Program for Load-Zoning Analysis (PLZA): User's Guide"

Ordering Information

This program takes the given data, predicts how many years the pavement would last until the next resurfacing or rehabilitation, and determines whether axle weight restrictions are required. It establishes what the axle weight restriction (if any) should be and then iterates through different axle weights until it reaches one that satisfies the given desired life of the pavement. The accompanying PLZA User's Guide includes instructions on not only running the program, but also on collecting the input data prior to evaluation.

According to Fernando, the issue of load weights and pavement life affects everybody. "There has to be a way to satisfy both sides-the need to move freight versus the need to preserve the highway infrastructure." With new tools such as PLZA becoming available, the process of improving our roads at lower costs will continue to move forward.

Texas Transportation Institute

Please send comments, suggestions, and queries to the TTI Webmaster, webmasters@ttimail.tamu.edu.
Texas Transportation Institute · Texas A&M University System · 3135 TAMU · College Station, Texas 77843-3135
979-845-1713 · 979-845-9356 (FAX)

TAC NEWS

A quarterly newsletter of the
Transportation Association of Canada

Volume 28 ~ Spring 2002

New U.S. Pavement Design Guide Will Have Major Impacts in Canada

Editor's Note: In this contribution to TAC News, *David Hein, principal engineer,* ***ERES Consultants****, a division of Applied Research Associates Inc., writes about benefits expected to flow from the upcoming release of the 2002 Pavement Design Guide of the American Association of State Highway and Transportation Officials.*

Canada's roads keep our society mobile and contribute in a major way to our economic infrastructure. The significance of the economical design and, more particularly, preservation of these valuable national assets cannot be overstated.

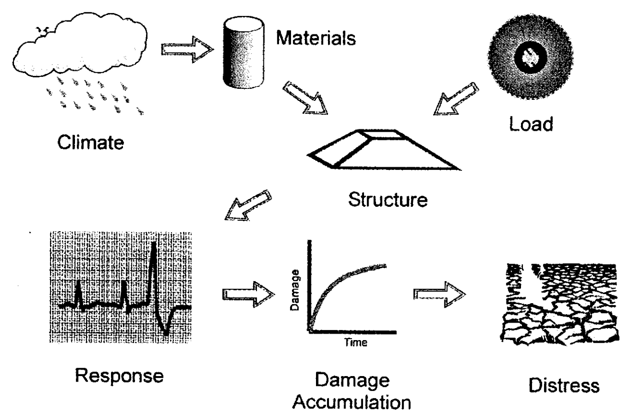
TAC and its volunteer committees have long recognized the importance of our road infrastructure. Research and development activities such as the Canadian Strategic Highway Research Program (C-SHRP) and technical guidance publications such as TAC's *Pavement Design and Management Guide* have made significant contributions to the improvement of pavement design, rehabilitation and maintenance and to the construction of long-lasting pavements with lower service costs.

One of the pavement design and rehabilitation procedures most widely used in the United States and Canada was developed by the American Association of State Highway and Transportation Officials (AASHTO). The current AASHTO design procedure (published in 1993 with a revision to the concrete design procedure in 1998) is an empirical method based on the findings of the extensive road test conducted in the 1950s by the organization's predecessor (AASHO). While AASHTO's design procedures have served remarkably well to date and have been updated regularly, the concepts have not changed substantially from the empirical method. Today's pavements experience heavier traffic, higher tire pressures and different axle load configurations than those common at the time of the AASHO road test. Moreover, new materials and construction practices requiring innovative design and evaluation techniques are constantly being introduced.

The potential cost savings resulting from an increase in pavement service life or a reduction in maintenance and rehabilitation costs is enormous. Recognizing the need for the development of a new design procedure to accommodate changes in pavement materials and loading, the AASHTO Joint Task Force, along with the U.S. National Cooperative Highway Research Program (NCHRP), commissioned the preparation of the 2002 edition of the AASHTO Pavement Design Guide (NCHRP Project 1-37a).

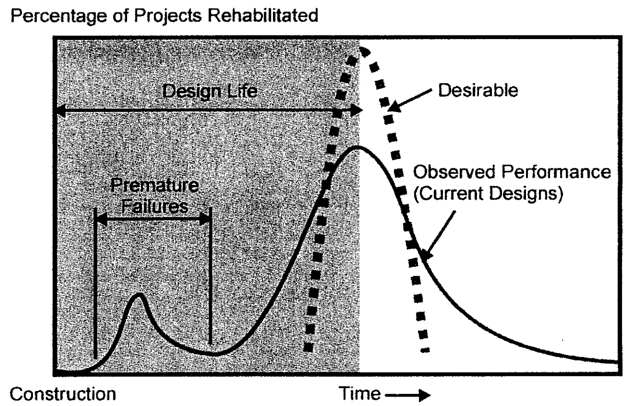
Entitled the *2002 Guide for the Design of New and Rehabilitated Pavement Structures,* the publication is very extensive and comprehensive. It includes procedures for the analysis and design of new and rehabilitated rigid and flexible pavements, procedures for evaluating existing pavements, subdrainage design methods, recommendations on rehabilitation treatments and foundation improvements and life-cycle cost analysis techniques. Finally, and probably most importantly, the publication provides guidance for calibrating design and rehabilitation procedures to local conditions and for developing agency-specific catalogs. The design procedures used in the guide are based on mechanistic-empirical concepts, which are a quantum leap forward from the old AASHO road test empirical designs. Mechanistic-empirical design focuses on pavement performance and accounts for all design features that directly affect pavement performance such as materials, climate, traffic loads and construction procedures.

Mechanistic-Empirical Design Concepts



AASHTO's 2002 mechanistic-empirical design method is a hierarchical or multi-level procedure based on design data requirements reflecting roadway classification. A significant change from previous methods is the use of vehicle axle load spectra (axle load distribution) rather than equivalent single axle loads (ESALs) to evaluate pavement loading over service life. AASHTO's 2002 guide also incorporates the latest technologies in materials characterization and in the use of climate data through the application of an enhanced integrated climate model (ICM). By using the ICM, variations in material and subgrade properties specific to local temperatures, humidity and precipitation are all factored into the design process.

Potential Pavement Cost Savings



The benefits of the 2002 AASHTO guide include the following:

- Inherent variations in materials, traffic and environmental factors and in construction processes are considered in the design analysis such that there are rational relationships between construction and materials specifications and the design of the pavement structure. The improved relationship between design and real pavement life means agency managers will be better able to weigh life-cycle costs and cash flow in their decision-making processes.
- Cost-responsibility studies will be enhanced by the improved ability to evaluate the consequences of new pavement loading conditions and the damaging effects of increased loads, high tire pressures and multiple axles.
- Designers will be better able to use available and evolving materials and, in many cases, the expected benefits of those materials will be modeled and evaluated without the expense of elaborate testing programs.
- Better diagnostic techniques will allow for improved evaluation of premature pavement failures.
- Improved environmental data and analysis will permit a better assessment of the effects of aging as well as that of the freeze-thaw cycle and the provision of improved drainage.
- Unlike typical regression-based empirical procedures, mechanistic concepts are generally applicable in such a way that a full range of future enhancements can be readily developed and implemented. Therefore, the new procedure will not become outmoded with changes in construction materials, traffic patterns, vehicle types or tire types and configurations.

In summary, AASHTO's 2002 design guide and its associated software and training courses are expected to provide pavement designers and government agencies not only in the United States but also in Canada with a strong set of tools to help effectively manage road infrastructure.

More information on the guide is available from AASHTO's Web site.

news@tac-atc.ca

Transportation Association of Canada, 2323 St. Laurent Blvd., Ottawa K1G 4J8
Tel. (613) 736-1350 ~ Fax (613) 736-1395

Design, Construction and Materials Illinois Department of Transportation
PTA-D2 (Eff. 04/1997, Rev. 02/2005) Bureau of Materials and Physical Research

PAVEMENT TECHNOLOGY ADVISORY

-TEMPORARY LOAD LIMITS ON LOCAL ROADS-

PTA-D2

WHY SET LOAD LIMITS?

The 18,000-pound Equivalent Single **Axle** Load (ESAL) is a standard measure of the damage applied to a **pavement** by traffic **loads**. As such, a vehicle that applies 2 ESALs to the **pavement** does twice the damage as a vehicle that applies 1 ESAL. However, the damage caused by each vehicle is not a simple linear increase with the vehicle weight. A general rule is that a 10 percent increase in gross vehicle weight will result in twice the damage to the **pavement**. By that reasoning, a load limit reducing the allowable vehicle weight by 10 percent could conceivably reduce the rate of **pavement** damage by one-half, and thereby double the **pavement life**.

LOAD LIMIT LAWS

While load limits may be an attractive way to reduce damage and extend the **life** of a **pavement**, they should not be overly restrictive. **Pavement** managers not only must protect the roads and the tax dollars [illegible] loading at other times of the year, and the reduced load limit may cause an undue inconvenience if left in place.

LOAD LIMIT EVALUATION

Two types of temporary load limits may be used: gross load or **axle** load. Gross load limits restrict the ***total*** weight of the truck, and **axle** load limits restrict the weight of each ***axle*** on the truck. The benefit of either load limit type can be evaluated by comparing the expected **pavement** damage under a temporary load limit reduction to the damage that would occur if no such reduction were imposed.

Example:

A local agency is considering a temporary load limit reduction on a section of roadway. The flexible **pavement** consists of 6 inches of crushed stone with a number of seal coats built up over the years. The local agency would like to know whether an 8,000-pound **axle** load limit or a 20,000-pound gross load limit invested in them; they must also provide transportation facilities that meet the users' needs without undue inconvenience. Load limit laws are intended to balance these missions.

In Illinois, one such law allows temporary load limit reductions on local roads for up to 90 days in one calendar year. The reason for the law is that the roadbed can become extremely soft at certain times of the year, typically during the spring thaw. At such times, the **pavement** may be severely damaged by only a few passes of heavy trucks. Alternatively, the **pavement** may be adequate for heavier

will provide a greater benefit.

Step 1 - Determine traffic:

Data is collected to determine the average daily traffic and the breakdown of vehicle types. Assume that a traffic count at the location yielded the following results (passenger vehicles ignored):

Truck Type	Daily Traffic
2-**Axle** (6-tire)	5
3-**Axle** (Tandem)	5
5-**Axle** (Semi)	5

Step 2 - Calculate the damage under an 8,000-pound axle load limit:

Equivalency factors represent the number of ESAL applications per vehicle. To determine the total daily damage to the **pavement**, the equivalency factor for each truck type is multiplied by the daily traffic for that truck type, and the results are summed. The equivalency factors for trucks of each type having 8,000-pound **axle loads** are highlighted in Table 1 on Page 3 of this document.

Truck Type	Daily Traffic
2-**Axle** (6-tire)	5 x 0.060 = 0.30
3-**Axle** (Tandem)	5 x 0.071 = 0.36
5-**Axle** (Semi)	5 x 0.110 = 0.55
Total daily damage	1.21

Step 3 - Calculate the damage under a 20,000-pound gross load limit:

The same process used in Step 2 is employed to calculate the total daily damage under a 20,000-pound gross load

For this example, assume that trucks of each type carrying the maximum legal load have the following load distributions.

Equivalency factor for 2-axle trucks:

18K 18K
↓ ↓
O O
1.00 + 1.00 = 2.00 ESALs/veh

Equivalency factor for 3-axle trucks:

32K 18K
↓ ↓
OO O
0.810 + 1.00 = 1.81 ESALs/veh

Equivalency factor for 5-axle trucks:

32K 32K 9.28K
↓ ↓ ↓
OO OO O
0.810 + 0.810 + 0.06 = 1.68 ESALs/veh

The daily damage from trucks carrying the maximum legal load would be:

limit. The equivalency factors for trucks of each type having 20,000-pound gross **loads** are highlighted in Table 2 on Page 3 of this document.

Truck Type	Daily Traffic
2-**Axle** (6-tire)	5 x 0.265 = 1.32
3-**Axle** (Tandem)	5 x 0.033 = 0.16
5-**Axle** (Semi)	5 x 0.008 = 0.04
Total daily damage	1.52

Step 4 - Calculate the damage under maximum legal load limits:

Equivalency factors for trucks carrying the maximum legal **loads** can be determined using Table 3 on Page 4 of this document, provided the designer knows the **axle** configuration and load distribution for the vehicle types. If only the gross vehicle weight is available, either the legal loading method, or the equal tire loading method *(see PTA-D1)* can be used to estimate the load distribution. Loading values that fall between the values listed in Table 3 can be estimated using linear interpolation.

Truck Type	Daily Traffic
2-**Axle** (6-tire)	5 x 2.00 = 10.00
3-**Axle** (Tandem)	5 x 1.81 = 9.05
5-**Axle** (Semi)	5 x 1.68 = 8.40
Total daily damage	27.45

Step 5 - Compare the damage caused under the different load limits

In this case, the maximum legal load limits would result in about 20 times more daily damage than if an 8,000-pound **axle** limit or a 20,000-pound gross load limit were imposed (27.45 ESALs vs. 1.21 ESALs or 1.52 ESALs, respectively). The daily **pavement** damage under a 20,000-pound gross limit is about 26 percent greater than the damage under an 8,000-pound **axle** limit; therefore, the 8,000-pound **axle** limit would be the preferred alternative.

Note: An 8000-pound **axle** limit results in substantial differences in the allowable gross load, depending on the number of axles per truck. The allowable gross **loads** must not exceed any bridge load limits that exist on the roadway section.

The basic process outlined in the previous example can be followed in the same manner to compare other load limit alternatives. The maximum legal load limits for use in Step 4 may be found on the Illinois Department of Transportation (IDOT) Designated State Truck Route System map, available upon request by calling (217)782-6271.

For help in establishing load limits, customizing loadings for unique situations, or for additional information, please contact:

Pavement Technology Engineer
Bureau of Materials and
Physical Research
126 East Ash Street
Springfield, IL 62704-4766
(217) 782-7200

TABLE 1: AXLE LOAD EQUIVALENCY FACTORS FOR FLEXIBLE PAVEMENTS

AXLE LOAD, KIPS	2-AXLE TRUCK	3-AXLE TRUCK	5-AXLE TRUCK
8	0.060	0.071	0.110
10	0.150	0.180	0.280
12	0.330	0.390	0.620
14	0.650	0.770	1.220
16	1.180	1.400	2.210
18	2.000	-	-

TABLE 2: GROSS LOAD EQUIVALENCY FACTORS FOR FLEXIBLE PAVEMENTS

GROSS LOAD, KIPS	2-AXLE TRUCK	3-AXLE TRUCK	5-AXLE TRUCK
12	0.031	-	-
16	0.100	0.015	-
20	0.265	0.033	0.008
24	0.575	0.073	0.017
28	1.130	0.135	0.030
30	1.555	0.180	0.040
32	2.100	0.235	0.050
36	-	0.395	0.075
40	-	0.610	0.110
44	-	0.950	0.170
48	-	1.390	0.240
50	-	-	0.280
52	-	-	0.340
56	-	-	0.470
60	-	-	0.620
64	-	-	0.835
68	-	-	1.090
72	-	-	1.400
76	-	-	1.780
80	-	-	2.210

TABLE 3: EQUIVALENCY FACTORS FOR SPECIFIC AXLE TYPES

LOAD, KIPS	FLEXIBLE PAVEMENT AXLE TYPE SINGLE	FLEXIBLE PAVEMENT AXLE TYPE TANDEM	RIGID PAVEMENT AXLE TYPE SINGLE	RIGID PAVEMENT AXLE TYPE TANDEM
2	0.0002	0.0000	0.0002	0.0001
4	0.002	0.0003	0.002	0.0006
6	0.009	0.001	0.011	0.002
8	0.030	0.003	0.035	0.006
10	0.075	0.007	0.087	0.014
12	0.165	0.013	0.186	0.028
14	0.325	0.024	0.353	0.051
16	0.589	0.041	0.614	0.087
18	1.00	0.066	1.00	0.141
20	1.61	0.103	1.55	0.216
22	2.49	0.156	2.32	0.319
24	3.71	0.227	3.37	0.454
26	5.36	0.322	4.76	0.629
28	7.54	0.447	6.58	0.852
30	10.4	0.607	8.92	1.13
32	14.0	0.810	11.9	1.48
34	18.5	1.06	15.5	1.90
36	24.2	1.38	20.1	2.42
38	31.1	1.76	25.6	3.04

ASSUMPTIONS FOR TABLES

- Table 1 assumes the load is shifted to achieve an equal load distribution to each **axle** (e.g. the gross load is divided by the number of axles to find the **axle** load).
- Table 2 assumes the following load distributions, typical under normal loading:

65% 35% 70% 30% 40% 40% 20%

↓ ↓ ↓ ↓ ↓ ↓ ↓

O O OO O OO OO O

2-axle truck 3-axle truck 5-axle truck

Note: Load distributions that differ significantly from these assumptions will have different associated equivalency factors. These can be determined individually if the situation arises. Contact the **Pavement** Technology Engineer for help.

- The equivalency factors in Tables 1 and 2 were compiled from the 1993 *AASHTO Guide for Design of* ***Pavement*** *Structures (AASHTO Guide)*, and are suitable for flexible pavements on the local roads system in Illinois. The values assume a **pavement** Structural Number (SN) of 1 and a terminal serviceability (p_t) of 2.0.
- The equivalency factors for Table 3 were compiled from the 1993 *AASHTO Guide*; SN = 1, T = 6, p_t = 2.0. The values are suitable for most flexible and rigid pavements on the local road system in Illinois. Table 3 can also be used for **pavement** design.
- The equivalency factors in all three tables apply to the roadway only, and do not apply to bridges or drainage structures.

TWEET User Guide

SOFTWARE TOOL TO PREDICT PAVEMENT-LIFE EFFECTS OF TRUCK WEIGHT ENFORCEMENT

Michael W. Goelzer, Fred R. Hanscom, and Kenneth H. McGhee

Transportation Research Corporation
2710 Lookout Road, Haymarket, VA, 20169, U. S. A.

Abstract

This paper describes a pavement management decision-making aid, a software package to predict the effect of truck weight enforcement on pavement life. The software program, **Truck Weight Enforcement Effectiveness Tool (TWEET)**, was developed (under the United States' National Cooperative Highway Research Program) to assist highway agencies in determining the effectiveness of truck weight enforcement programs. The software takes into account the reduction of WIM-measured ESALs observed to be associated with truck weight enforcement programs.

The software user essentially conducts a pavement design-life enforcement-effects analysis. Default pavement design values for both flexible and rigid pavements are provided by the software to assist the user. Operation of the software requires Weigh-in-Motion (WIM) data collected under varying conditions of truck weight enforcement. The software determines pavement life differences based on observed truck axle weights.

1.0 INTRODUCTION

A key to managing pavements is the development of appropriate tools to aid decision-makers who are responsible for pavement design, construction and maintenance. A critical element in pavement wear is the effect of heavy trucks, and a significant consideration to pavement managers is the real impact of truck weight enforcement, i.e., the impact on weight violations to pavement service life.

The Truck Weight Enforcement Effectiveness Tool (TWEET) is a software application developed under NCHRP Project 20-34 and designed to aid users in determining the effectiveness of user-specified truck weight enforcement activities. It works by reading WIM data which has been collected under two user-designated enforcement conditions, and it allows the user to compare M.O.E. data from each condition so as to determine the more effective enforcement method.

2.0 EFFECTS OF AXLE WEIGHT ENFORCEMENT ON PAVEMENT LIFE

One of the basic premises of truck weight enforcement is that there will be a net increase in pavement life (reduction in the rate of pavement deterioration). The following discussion summarizes two methods of determining the increase in pavement life one could expect from reduced axle loadings accrued through enforcement activities. The methods makes use of an AASHTO design procedure (1) providing for the traffic input to design to be in terms of accumulated (or projected) 18,000 lb. equivalent single axle loads (ESALs).

In their approach, AASHTO uses the definition: "Load equivalency factors represent the ratio of the number of repetitions of any axle load and axle configuration (single, tandem, tridem) necessary to cause the same reduction in Present Serviceability Index (PSI) as one application of an 18-kip single axle load."(1). Thus, an axle load with an 18-kip equivalency of 2.5 could be considered to be 2.5 times more damaging than the 18-kip loading.

The general approach is to determine the cumulative ESALs a given pavement is capable of sustaining before it's serviceability is reduced to an unacceptable level, i.e., the design load capacity. Then, the traffic stream using that pavement is analyzed both before and after enforcement efforts are implemented to determine the effects of that enforcement on daily ESALs generated by the stream. Finally, the daily ESALs before and after enforcement are used to determine the estimated times (before and after enforcement) required to consume the load capacity.

AASHTO design procedures provide for the traffic input to design to be in terms of accumulated (or projected) 18,000 lb. equivalent single axle loads (ESALs). In their approach, AASHTO uses the definition: "Load equivalency factors represent the ratio of the number of repetitions of any axle load and axle configuration (single, tandem, tridem) necessary to cause the same reduction in Present Serviceability Index (PSI) as one application of an 18-kip single axle load."(1). Because of that definition, many designers view the equivalency factor of a given axle load to be a relative measure of pavement damage inflicted by that load.

The serviceability index (PSI or p) is a subjective measure of pavement condition on a 0 to 5 scale with 0 defined as unusable and 5 defined as perfect. While there are many variations, a typical new road will have an initial serviceability (p0 or PSI at time 0) of about 4.4 while the terminal or no longer acceptable serviceability (pt) generally ranges from 2.0 to 3.0.

Unfortunately, the analysis of traffic data from a pavement design standpoint is greatly complicated by the fact that the relationship between axle loads and ESALs (equivalency factor) is geometric rather than linear and the relationship is a function of pavement structural capacity as well the level-of-service at which the pavement is considered to have failed (the terminal PSI). Further, the relationships differ for flexible and rigid pavements. ESAL equations for both types of pavements and for single and tandem axle loads were derived from the AASHO Road Test (2). Relationships for tridem axles have been developed through other research to extend the Road Test results (3).

The ESAL equivalency factor equations for flexible pavements are:

Equation (1): $\log10(wx/w18) = 4.79*\log10(18+1) - 4.79*\log10(Lx+L2) + 4.33*\log10 L2 + Gt/bx - Gt/b18$

Equation (2): $Gt = \log10[(4.2 - pt)/2.7]$

Equation (3): $bx = 0.40 + [0.081*(Lx + L2)^{3.23}]/[(SN + 1)^{5.19}*L2^{3.23}]$

where

wx = number of loads of magnitude Lx required to reduce the PSI to pt,

w18= number of 18 kip loads required to reduce the PSI to pt,

Lx = load on one single axle or one tandem axle set (kips),

L2 = axle code (1 for single axle and 2 for tandem axle),

SN = pavement structural number (see Section 6 for examples of SN determination),

pt = terminal serviceability (on a 0 to 5 scale typical pt values are 2.0, 2.5, and 3.0), and

b18= value of bx when Lx = 18 and L2 = 1.

For rigid pavements, the equations are:

Equation (4): log10(wx/w18) = 4.62*log10(18+1)-4.62*log10(Lx+L2) + 3.28*log10L2 + Gt/bx - Gt/b18
Equation (5): Gt = log10[(4.5 - pt)/3.0]
Equation (6): bx = 1.00 + [3.63*(Lx + L2)^5.20]/[(D + 1)^8.46*L2^3.52]

where D is the slab thickness in inches.

3.0 SOFTWARE APPLICATION

The software package, Truck Weight Enforcement Effectiveness Tool (TWEET), applies the above pavement design principles in determining the impact of user-specified truck weight enforcement activities. The program runs on any version of Windows. Its running time will depend upon a number of factors, i.e., vehicle sample size and host computer operating characteristics (e.g., the megahertz rating). The software has demonstrated outstanding efficiency, processing tens of thousands of truck weights in less than a minute.

This software presents the user with a variety of "dialog boxes", i.e., pop-up screens which enable the user to provide required input to run the software. The software is designed to be user friendly, e.g., in most cases the user will simply press the "Next" button to continue operation based on the program's output.

To start a truck weight enforcement analysis, the user would press the Start Analysis button in the program's main window (See figure 1 on the next page) as the program begins. Three discrete steps to the data analysis and interpretation process are as follows.

3.1 User Input

The program requires the user to enter such information as the applicable units the program is to use (i.e., English or Metric system), WIM data file format (if non-typical) , and legal weight limits. Default values are provided to assist the user.

3.2 Calculations

The program performs necessary M.O.E. calculations based on WIM data contained the user's files. This calculation process is automatically performed by the program, and the user need not be concerned with this part of the program. During calculations, a graphical percentage-completion indicator is displayed to advise the user of the program's activity.

3.3 Output

Calculated Measures of Effectiveness (M.O.E.s) are displayed to the user. On-screen reports are displayed in a series of dialog boxes, each of which permit by the user to print out calculated results. The program will automatically display calculated values. Once the program has performed all the calculations, output can be viewed again by pressing the View Results button on the main window. Summary output can be printed out via the Print Results button.

4.0 PROGRAM OPERATION

Start the TWEET program, and the Main Window (see Figure 1on the next page) dialog box will appear.

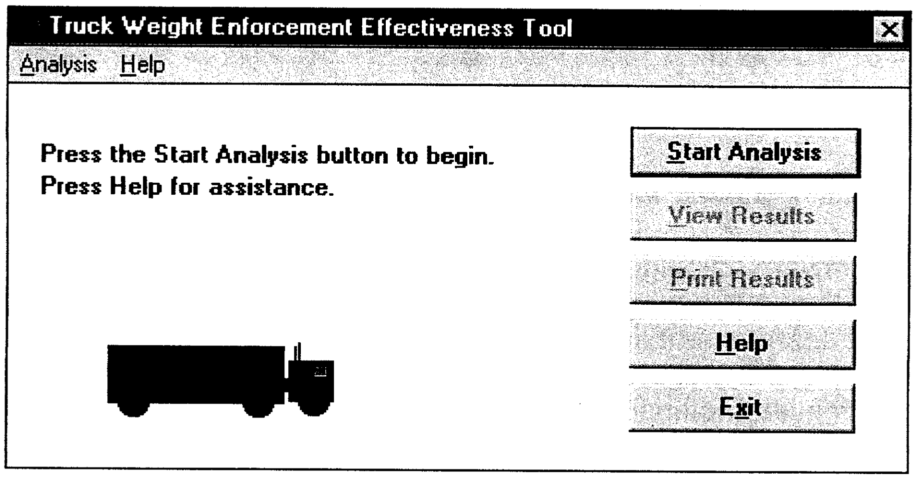


Figure 1. "Main Window" on M.O.E. Application Software

From the main window, press the button marked "Start Analysis." This will allow the user to start a truck weight analysis and enforcement effects. First the user will encounter a dialog labeled Select Units. See Figure 2 below.

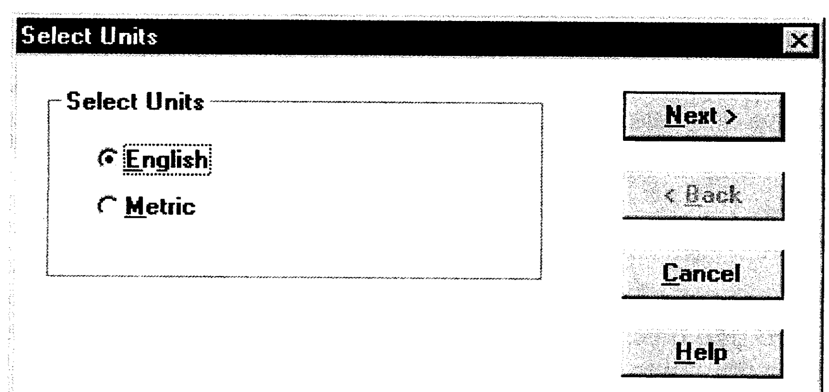


Figure 2. "Select Units" Dialog Box

ACPA

American Concrete Pavement Association

CONCRETE PAVEMENT PROGRESS

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This month ... *Design and Construction of Streets & Local Roads.*

Next month ... *ACPA revisits sound at the tire/pavement interface.*

Concrete Pavement Answers Funding Challenges

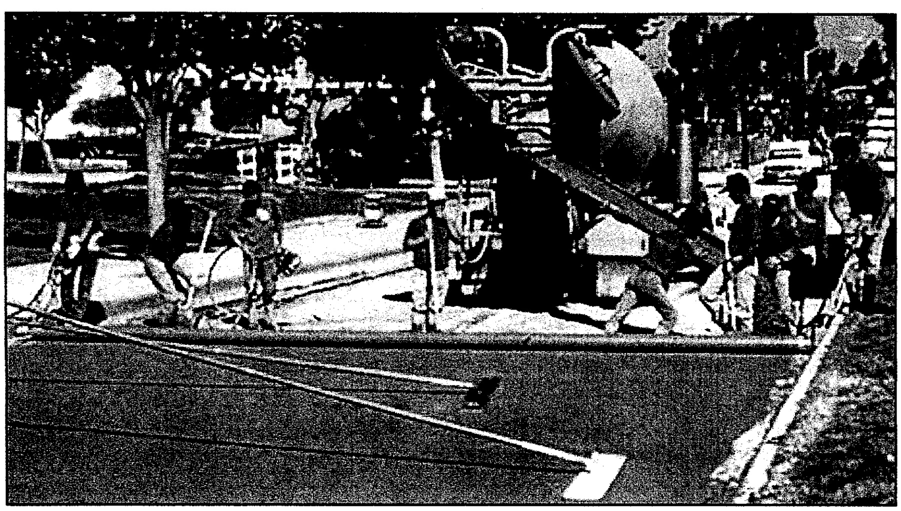
By Scott Haislip
Director of Streets & Local Roads
American Concrete Pavement Association, Skokie, Ill.

Increasingly, state and local governments are facing the challenges of securing and managing funding for street construction and improvement. Deteriorating transportation infrastructure and cyclical application of short-term resurfacing puts enormous pressure on budgets and is forcing administrators to use asset management strategies to meet GASB 34 requirements (Ref 1).

Concrete pavements can help meet those funding challenges. With innovative techniques and a range of solutions, concrete pavements are competitive with asphalt pavements. Extended pavement life, lower life cycle costs, innovative techniques and products, and reliable performance contribute to a greater long-term value. Agencies on the hunt for roadway dollars can use these benefits to create a convincing argument for funding.

Asset Management

Within the scope of asset management, pavement management includes evaluating the existing pavement network and balancing construction improvement activities. The goal is to maintain pavements and even out the expenditure flow by employing long-term concrete solutions with short-term asphalt resurfacing.



The extended life, lower life cycle costs, and reliable performance of concrete pavements contribute to a greater long-term value over asphalt.

Life Cycle Cost Analysis
To determine the cost effectiveness of individual projects, many agencies use life cycle cost analysis (LCCA) to examine the economic benefits of competing alternatives. The process takes into account the cost and value of a particular asset over a period of time, and then enables agencies to make the best pavement decision.

According to the Federal Highway Administration's Office of Asset Management, there are five steps of a successful life cycle cost analysis. They are: establish design alternatives; determine activity timing; estimate costs (agency and user); compute life-cycle costs; and analyze the results.

Remaining Service Life
Remaining service life is an important component of life cycle cost analysis. It involves measuring the longevity of a competing alternative after the life cycle period ends. Remaining service life evaluations are very telling about the intrinsic value of concrete pavements, as this will typically show concrete lasting years after asphalt pavements fail.

The addition of concrete pavements can dramatically increase the life of the overall network of roads, decreasing the required maintenance cycle. Concrete pavements cut the amount of annual repairs by spreading them out over longer time periods ultimately lowering the maintenance expenditures and budget.

Mix of Fixes
Pavement networks can be optimized with concrete through a variety of methods. They include: regular maintenance; concrete pavement restoration; resurfacing with overlays; full-depth reconstruction; and fast track paving.

Innovative techniques and a variety of flexible solutions make concrete pavements a solid long-term choice, offering excellent service, safety, and value for end users. These benefits create a convincing argument for funding, even in today's challenging economy.

Endnotes
(1) A policy enacted by the Government Accounting Standards Board (GASB) in 1999, called GASB 34, requires that government agencies promote responsible asset management policies and strategies, treating infrastructure components like pavements, bridges, and airports as assets.

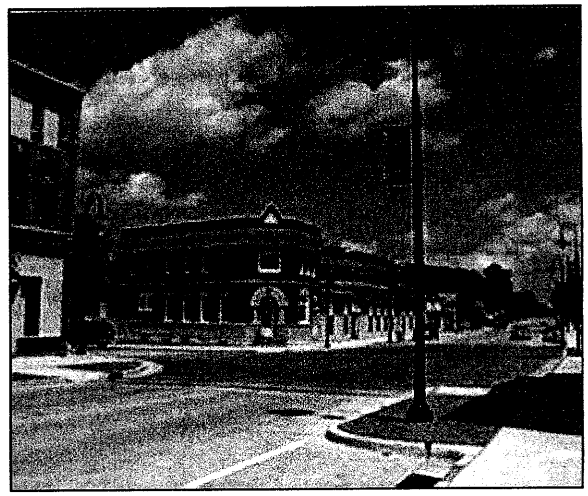
A Practical Approach to Designing City Streets

A pratical way to design city streets involves establishing a street classification system. Comprehensive traffic studies made within city boundaries show that streets of similar character have essentially the same traffic densities and axle load intensities.

A street classification system can provide an axle load distribution for the various categories of streets. There are six street classifications discussed here:

Light Residential streets are typically short and found in subdivisions, as well as other residential areas. They may have dead ends or turn-arounds. They serve traffic to approximately 20 to 30 lots or houses with low traffic volumes. They are also characterized by:
* VPD (Ref 1) - Less than 200/day
* ADTT (Ref 2) - 2 to 4/day
* Maximum loads (Ref 3) - 18 kip single axles/36 kip tandem axles.

Residential streets carry similar traffic as light residentials (except more of it), plus an occasional heavy truck. On a grid-type street system, these streets carry traffic serving up to 300 homes as well as collecting all light residential traffic within the era and distributing it into the major street system. They are also characterized by:
* VPD - 200 to 1000/day
* ADTT - 10 to 50/day
* Maximum loads - 22 kip single axles/36 kip tandem axles.



Main Street in the Village of Little Chute, Wis., is a collector street. It features traditional concrete pavement, colored and stamped concrete pavements; and colored and imprinted sidewalks. The recent reconstruction project was recognized by ACPA with an "Excellence in Concrete Pavement" award.

Collector streets collect traffic from several areas and maybe several miles long. They may be bus routes and serve truck movements to and from an area, although they are generally not considered through-routes. It's also characterized by:
* VPD - 1000 to 8000/day
* ADTT - 50 to 500/day
* Maximum loads - 26 kip single axles/44 kip tandem axles.

Business streets provide access to carry traffic through central business districts. Business streets are frequently congested and speeds are slow because of high traffic volumes, but with a low truck traffic percentage. They are also characterized by:
* VPD - 11,000 to 17,000/day
* ADTT - 400 to 700/day
* Maximum loads - 26 kip single axles/44 kip tandem axles.

Industrial - Industrial streets provide access to industrial areas or parks. Total traffic volumes may be low, but the percentage of trucks is high. They are also characterized by:
* VPD - 2000 to 4000/day
* ADTT - 300 to 800/day
* Maximum loads - 30 kip single axles/52 kip tandem axles.

Arterials - Arterials bring traffic to and from expressways and serve major movements within and through metropolitan areas not served by expressways. Arterials typically carry truck and bus routes. For design purposes, arterials are divided into major and minor arterials depending on traffic capacity and type. Minor arterials are characterized by:
* VPD - 4000 to 15,000/day
* ADTT - 300 to 600/day
* Maximum loads - 26 kip single axles/44 kip tandem axles.
Major arterials are characterized by:
* VPD - 4000 to 30,000/day
* ADTT - 700 to 1500/day
* Maximum loads - 30 kip single axles/52 kip tandem axles.

Endnotes
(1) VPD - Vehicles per day.
(2) ADTT - Average daily truck traffic and axle-load distributions. This design method uses the average daily truck traffic in *both* directions to model the loads on the concrete pavement. For design purposes, this traffic is assumed to be equally distributed in each of the two directions (i.e., 50 percent each way). The ADTT value includes only trucks with six tires or more and does not include panel and pickup trucks or other four-tire trucks.
3) kip - One kip is a unit of measure equal to 1,000 pounds.

Tech Tip

Sampling Fresh Concrete

Tips to ensure accurate, representative samples

On almost every concrete paving project, the contractor or concrete supplier must demonstrate that a quality product is being supplied and delivered to the construction site. This typically requires the contractor to sample fresh concrete.

Improper handling or sampling may result in inaccurate strength, air, slump, or temperature measurements. Here are a few tips on sampling fresh concrete:

1. Sample Size - Obtain at least 1 cubic foot (0.03 cubic meter) of concrete for strength tests. If combining tests (e.g., air, slump, and strength from same batch), sample enough concrete to fill about two thirds of a standard wheelbarrow.
2. Handling - Use a scoop or shovel, wheelbarrow, or plastic sheet. Remember that other equipment is needed for the appropriate tests, such as beam or cylinder molds, slump cone, rod, air pot, etc. Transport the sample to where the fresh concrete tests are to be performed, remix as needed, and cover it with a plastic sheet to prevent evaporation.
3. Precautions - Make the sample as representative as possible. Do not restrict flow from mixers. Guard against segregation of concrete during sampling.

Taking samples differs based on whether it comes from a mixer, truck, or container. Here are some considerations keyed to each type:

Paving Mixers - Collect samples from five different places in the pile (i.e., end dump truck) after discharge of the mixer.
Other Stationary Mixers, Revolving-Drum Truck Mixers, or Agitators - Sample at two or more regular intervals at about the middle portion of the batch. Either pass a receptacle through the entire discharge stream or divert the stream completely.
Open Top Mixers or Containers - Use either method above, whichever is more applicable.

For more information on sampling fresh concrete, see Portland Cement Association (PCA) publication PA015.05. To order, visit PCA's website, www.cement.org. Contact Steve Waalkes at 847-966-2272 if you have any questions about this article.

THE EFFECTS OF HIGH MASS LIMITS ON ROAD PAVEMENTS

A. Barrie and M. Windress

James Goldston Faculty of Engineering and Physical Systems
Central Queensland University, Rockhampton, Australia

ABSTRACT

Heavy vehicle performance (suspension, payload, engine horsepower etc) and axle configurations have changed dramatically over the past ten years, improving the efficiency of road freight vehicles to allow for increases in the road freight task. These increases in the road freight task have led to changes in the axle masses of heavy vehicles. The impact of these increases in axle mass need to be evaluated for the road infrastructure of Australia, so that changes to mass limits can be made to boost the productivity of the nation's transport fleet.

This report details the investigation into the effects of these axle mass increases, or High Mass Limits, on road pavements in regards to pavement loading and the subsequent pavement wear produced by heavy vehicles, pavement design procedures, pavement maintenance and construction costs and procedures, the operation of the road transport industry and the social impacts of the introduction of HML.

1.0 INTRODUCTION

In 1999, the Queensland government authorised the use of High Mass Limit (HML) vehicles on the national highway system and approved B-double routes. The introduction of High Mass Limits led to an increase in the maximum allowable axle masses of heavy vehicles provided that they were fitted with a certified Road Friendly Suspension (RFS) system. These RFS systems greatly improve the dynamic loading performance of heavy vehicles, which is the main factor in road pavement failure. [1]

1.1 High Mass Limits

Although the introduction of HML has led to an increase in allowable axle mass limits, this increase only applies to specific axle groups. The increases in axle mass provided by introduction High Mass Limits are as follows:

- 0.5 tonne increase on tandem axle groups fitted with 8 tyres.
- 2.5 tonne increase on tri-axle groups with 12 tyres.
- 1.0 tonne increase on single drive axles on buses.
- 1.0 tonne increase on six-tyred tandem axles.
- For long combination vehicle prime movers, fitted with wide single tyres (at least 375mm), the steer axle mass shall not exceed 6.7t. [2]

From these, HML axle masses for all heavy vehicle axles can be identified as.

Axle Type	Tyre Type	HML Axle Mass
Single Axle	Single tyres	6.0 t
	Wide single tyres	6.7 t
	Dual tyres	9.0 t
Dual Axle	Single tyres (Dual Steer)	11.0 t
	Single & dual tyres	**14.0 t**
	Dual tyres	**17.0 t**
Tri-Axle	Single tyres	15.0 t
	Dual or wide single tyres	**22.5 t**

1.2 Road Friendly Suspension Systems

Heavy vehicle suspensions control the way in which the vehicle's dynamic axle loads are transmitted to the road pavement. The standard suspension systems employed on heavy vehicles are constructed using rigid laminated steel springs. To reduce the dynamic axle loads on road pavements, Road Friendly Suspension systems were introduced. RFS systems reduce the axle loads produced by heavy vehicles by introducing a Road Friendly Pavement Wear Reduction Factor (RFPWRF) to the calculation of dynamic pavement loading (Equivalent Standard Axles or ESAs). The road friendly reduction factors applicable for HML axle masses are;

Axle Group	Tyre Type	RFPWRF
Singe axle	Single tyres	1.00
Single axle	Dual tyres	1.15
Tandem axle of prime mover	Dual tyres	1.25
Tandem axle of trailer	Dual tyres	1.20
Tandem axle	Dual & single tyres	1.20
Tri-axle	Dual tyres	1.20

2.0 METHOD OF INVESTIGATION

2.1 Pavement Wear

The method that was used to quantify the effect of HML on pavement wear was a comparison of calculated ESA-km of travel by heavy vehicles for Non-HML (0% RFS use) and various levels of HML axle loads (50%, 75% & 100% RFS use). This value was used to measure the pavement loading (and therefore wear), and is the product of the number of Equivalent Standard Axles (ESAs) and the Annual Distance Travelled (ADT).

The ADT for each heavy vehicle class were calculated using data from the *Survey of Motor Vehicle Use 2002* [3], and the ESAs for each class were calculated using the established 4th power rule. The standard form of the 4th power rule used to calculate Non-HML loading was;

$$\text{ESAs} = \left[\frac{\text{Actual Axle Load}}{\text{Reference Axle Load}}\right]^{n=4}$$

The adjusted form of the 4th power rule used to evaluate HML vehicles fitted with RFS systems was [4];

$$\text{Road Friendly Adjusted ESA} = \left(\frac{\left(\frac{\text{Actual Axle Load}}{\text{Reference Axle Load}}\right)^{n=4}}{\text{RFPWRF}}\right)$$

2.2 Pavement Design

The procedure that was evaluated to identify the effects of HML on pavement design procedures was the comparison of results from granular and cemented material pavement design charts for different pavement loading scenarios. These loading scenarios included design traffic ESA values calculated using Non-HML loading, HML loading for varying degrees of RFS use, and site specific data for both high and low traffic conditions, supplied by Queensland Department of Main Roads. Differing traffic data was used to compare the effects of HML on the design of road pavements for different traffic volumes. Pavement thicknesses were also calculated using design traffic values for pavements over subgrades of CBR 3, 5 & 10, to compare the effects of HMLs on the design of pavements on various sugrades.

2.2 Pavement Maintenance

The effects of HML on pavement maintenance costs and procedures were evaluated by analysing the reduction in reseal frequency and pavement service life due to the increase in the amount of pavement wear produced by heavy vehicles. This involved calculating a Pavement Wear Ratio (PWR), which is the ratio between the ESA-km values calculated for each level of HML loading and RFS use, and the ESA-km value for Non-HML pavement loading. Once calculated, the PWR was applied to the standard reseal frequencies and pavement service lives for pavements designed for both high and low traffic conditions.

2.3 Pavement Construction

Changes to pavement construction costs and procedures due to HML were also evaluated. This investigation was conducted by comparing the per kilometre cost of construction for both granular and cemented material pavements, on various subgrades, for both high and low traffic conditions. The cost of construction was calculated by applying unit rates for construction to the volume of pavement material required. The volume of pavement material was calculated by multiplying the depth of the pavement, by the calculated width of the road section by the one (1) kilometre length. The unit rates used were obtained from Department of Main Roads officers and were $\$65/m^3$ for granular material and $\$100/m^3$ for cemented material pavements.

2.4 Transport Industry Operation

The effects of HML on the operation of the road transport industry was evaluated by conducting a survey of large road freight companies (Q-Link, TNT, NQX and Toll). This survey was designed to obtain data on such areas of operation as percentage of RFS use, which heavy vehicle classes are employing HML loads, the cost of implementing HML, the benefits and problems of HML and the strategies employed by the companies in applying HML loads.

3.0 RESULTS AND ANALYSIS OF INVESTIGATIONS

3.1 Pavement Wear

The results of the pavement wear analysis showed an increase in the pavement loading and therefore the wear produced by Australia's heavy vehicle fleet as a result of the introduction of HML. Increases were also seen through the calculated ESA-km values for differing amounts of RFS use. The results recorded for pavement wear (ESA-km) were;

0% RFS Use (Non-HML)	50% RFS Use (HML)	75% RFS Use (HML)	100% RFS Use (HML)
32634.80×10^6	32755.45×10^6	32803.60×10^6	32859.87×10^6

Through further analysis it was found that although the overall value of pavement wear produced did increase with the introduction of HML, the wear produced by several classifications of heavy vehicles reduced. These vehicle classes were all rigid trucks and three (3), four (4) and five (5) axle articulated trucks. The main reason for the overall increase in wear was the substantial increase in the pavement loadings for articulated trucks with six (6) or more axles. This substantial increase in the wear produced by these vehicles can be attributed to the use of the dual tyred tri-axle axle configuration. This axle configuration received the greatest increase in the allowable mass limit (2.5 t) under HML and has only a moderate RFPWF of 1.2. It is the combination of this large mass increase and relatively small RFPWRF that has lead to dramatically increased pavement wear for these vehicles. This increase in wear for these vehicles is particularly important as they have the greatest rate of illegal vehicle overloading. Therefore, it has been recommended that steps be taken to reduce overloading in these vehicle classes, to avoid extensive wear and damage to road pavements. [5]

3.2 Pavement Design

The results of the pavement wear investigation were then transferred to the pavement design analysis as the pavement loading (ESA) data for the vehicle classes was used to calculate pavement design traffic for each level of HML loading. These design traffic values were then applied to Pavement Design Charts 1 & 13 [6] to obtain values for pavement thickness. The results gained for pavement depth for all conditions were;

Traffic Condition	Pavement Material	Subgrade CBR	Change Depth
High Traffic	Granular	3	5 mm
		5	5 mm
		10	5 mm
	Cemented material	3	5 mm
		5	0 mm
		10	0 mm
Low Traffic	Granular	3	10 mm
		5	10 mm
		10	10 mm
	Cemented material	3	5 mm
		5	0 mm
		10	0 mm

From the results it can be seen that the introduction of HML has led to the increase in pavement thickness for granular and cemented material pavements, on various subgrades, for both high and low traffic conditions. It has also been shown that the increase in pavement depth is greater for granular material pavements. This is because the evaluated increases in pavement loading have a lesser effect on thickness results obtained from the design curves for the cemented material pavement chart. The results also indicate that there is a greater increase in pavement depth for low traffic conditions.

Although there has been an small increase in the pavement depths due to HML, the amount of this increase is only between 5-10mm. Considering the Queensland Department of Main Roads pavement construction tolerances are +/- 15mm, the increases in pavement thickness observed due to the introduction of HML are fairly minimal and would be contained within this tolerance. However, as road pavements perform best when constructed as per design, the increases in pavement depth due to HML should still be recognised and incorporated into pavement design procedures.

3.3 Pavement Maintenance

The main objective of the pavement maintenance cost and procedure investigation was to evaluate the reduction in reseal frequency and service life of pavements due to HML. This was done by applying a calculated PWR to standard reseal and pavement life durations for high and low traffic conditions. The PWR values for the different levels of HML loading were calculated using the following formula;

$$PWR = \frac{\text{Total ESA-km (HML Traffic)}}{\text{Total ESA-km (Non-HML Traffic)}}$$

The results for the adjusted reseal frequencies and pavement service lives for the increased loading conditions were;

% RFS Use	PWR	Traffic Condition	Reseal Frequency	Pavement Service Life
0	1.0000	High	9.00 yrs	25.00 yrs
		Low	16.00 yrs	25.00 yrs
50	1.0037	High	8.96 yrs	24.90 yrs
		Low	15.94 yrs	24.90 yrs
75	1.0052	High	8.95 yrs	24.87 yrs
		Low	15.91 yrs	24.87 yrs
100	1.0069	High	8.94 yrs	24.82 yrs
		Low	15.89 yrs	24.82 yrs

From these results it can be seen that the changes in reseal frequency and pavement service life for both high and low traffic conditions are minimal. Therefore, the change in pavement maintenance cost as a result of HML can be assumed to be nil, as the effect of HML in increasing the pavement wear produced by heavy vehicles is not significant enough to reduce the frequencies of any road pavement maintenance activities.

3.4 Pavement Construction

The pavement thickness results from the pavement design investigation were transferred to the pavement construction analysis, as the calculated pavement depths for each level of the HML loading, subgrade and traffic conditions were used to estimate the volume of pavement material required. The volumes were then multiplied by the specified unit rates to calculate the pavement construction costs. These costs for the various pavement constructions were then compared to evaluate the increase in costs as a result of the introduction of HML. The increases in pavement construction costs found by the investigation were;

Traffic Condition	Pavement Material	Subgrade CBR	Change Cost
High Traffic	Granular	3	$7 150
		5	$7 150
		10	$7 150
	Cemented material	3	$11 100
		5	$0
		10	$0
Low Traffic	Granular	3	$7 150
		5	$7 150
		10	$7 150
	Cemented material	3	$5 500
		5	$0
		10	$0

From the results it can be seen that the introduction of HML has led to an increase in pavement construction costs. This increase can be seen to be greater for granular pavements, where the increase in pavement depths due to the increased pavement loadings is larger than for cemented material pavements. The increase in granular pavement construction costs is constant for all subgrades strengths, however for cemented material pavements, an increase only occurs for construction on subgrades of low strength (CBR 3). There is no cost increase for higher strength subgrades (>=5) as the increase in pavement loading due to HML has no effect on the pavement depth required.

3.5 Transport Industry Operation

From the results gained from the transport industry survey, many conclusions can be drawn about the effect of HML on transport industry operation. The results of the survey detailed that the rate of RFS use varies between 5-75%, however the most common figure is approximately 5-10%. The survey also details that the heavy vehicle classes employing RFS were two (2) and three (3) axle rigid trucks and articulated trucks with six (6) or more axles. The data obtained also explains that transport companies believe that RFS systems are more expensive to operate than steel systems, due to expensive maintenance costs, and that the conversion of the steel suspensions of existing fleet vehicles to RFS is not financially viable. The survey results also details that the rate of RFS use will increase by 10-25% within the next 5-10 years. Finally, the data also shows that most transport companies believe that the benefits of HML are increased productivity and payloads, leading them to maintain fleet vehicle numbers and increase productivity through increasing vehicle payloads. From this survey data, it can be assumed that the introduction of HML has led to the increase in productivity and efficiency of Australia's road transport fleet.

3.6 Social Impacts of HML

The investigation into the social impacts of HML were associated with three main areas; engine emissions, noise pollution and road safety. From the results of the transport industry survey and traffic data from the *Survey of Motor Vehicle Use 2002,* [7] it was found that the number of heavy vehicles in the Australian fleet had increased since the introduction of HML in 1999. However this increase was only due to traffic growth and was not directly linked to HML.

From this information on vehicle numbers, it was found that the overall engine emissions from heavy vehicles had slightly increased due to the introduction of high mass limits. This increase was caused by an individual HML vehicle's tendency to accelerate slower through power ranges than a Non-HML vehicle. Through the investigation of the noise pollution created by heavy vehicles, it was found that the introduction of HML has led to a reduction in the overall noise pollution level, due to a reduction in suspension/load noise between vehicle types. Finally, it was also found that because of the increase in heavy vehicle numbers that the exposure of traffic to heavy vehicle accidents had also increased. However, as there is no direct link between HML and the increase in heavy vehicle numbers, it can be assumed that the introduction of HML had no effect on the exposure rate of traffic to heavy vehicle accidents.

4.0 CONCLUSION

In conclusion, through the detailed research, planning and investigation carried out during both the planning and implementation phases of this project, it can be seen that introduction of High Mass Limits has led to many changes in road pavement loading, design and management. Several recommendations have therefore been made on the implementation of these changes.

- The increase in pavement loading produced by heavy vehicles as a result of the introduction of HML must be taken into account when designing road pavements.
- That greater measures be put in place by road network administrative bodies to identify overloaded vehicles and that new strategies be implemented to reduce the number of illegally loaded vehicles, as to reduce the increase in pavement loading.
- That the effect of HML on pavement maintenance procedures and costs be recognised, but that no additional action be taken.
- That the increase in pavement material volume and construction cost be recognised and incorporated into pavement construction procedure.

5.0 REFERENCES

[1][2] National Road Transport Commission, *Mass Limits Review*, National Road Transport Commission, 1996.

[3][7] Australian Bureau of Statistics (ABS), *Survey of Motor Vehicle Use – 12 Months Ending 31 October 2002,* ABS, 2002.

[4][5] Sweatman, P., *A Study of Dynamic Wheel Forces in Axle Group Suspensions of Heavy Vehicles,* ARRB Transport Research, 1983.

[6] Queensland Transport, *Pavement Design Manual,* Queensland Transport, 1990.

TECH**BRIEF**

LTPP

The Long-Term Pavement Performance (LTPP) program is a 20-year study of inservice pavements across North America. Its goal is to extend the life of highway pavements through various designs of new and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices. LTPP was established under the Strategic Highway Research Program, and is now managed by the Federal Highway Administration.

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

Why Does LTPP Require Site-Specific Traffic Loading Data?

PREPRINT

PUBLICATION NO.: FHWA-RD-98-103
LTPP Contact: Barbara Ostrom, HNR-30, (703) 285-2514

Introduction

The Long Term Pavement Performance (LTPP) program is a 20-year research study of in-service pavements. The program's results provide the basis for pavement design, maintenance, rehabilitation, and construction procedures and methodologies for years to come. As with any research endeavor, however, LTPP's results are strongly influenced by the quality, quantity, and completeness of the input data. LTPP, therefore, has very stringent data requirements. The purpose of this TechBrief is to discuss one of these requirements—site-specific measurements for estimating pavement loadings—and to illustrate the effects of traffic loading data error on LTPP's ability to develop accurate and reliable design equations.

Effects of Traffic Loading Data Error

Although statewide or regional average loads per vehicle may cost less to determine than site-specific loads (and may be appropriate for many other types of analyses), the use of traffic loading data that are not site-specific can produce significant errors in the annual, cumulative, and design life estimates of pavement loadings. LTPP and American Association for State and Highway Transportation Officials research[1] has shown that the use of average loads can have negative impacts on the reliability of pavement life predictions. These reliability concerns are magnified when the loading estimates are being used as one of the primary independent variables in the development of new design equations. The cost of errors in new design equations that may occur as a result of using poor loading estimates far exceeds the near-term data collection cost-savings that can be gained by using statewide and regional averages.

Volumes

That traffic load varies considerably from site to site is well documented. Load varies because the number, size, and configuration of trucks change from road to road, and because the loading condition of those trucks changes from location to location. These conditions can change dramatically even between two directions on the same road.

A Washington State study found that, on average, 7.1 percent of the traffic on its rural primary arterial system consisted of Federal Highway Administration

(FHWA) Class 9 trucks (five-axle tractor semi-trailers). However, the standard deviation of that estimate was almost 5.2 percent. This means that more than 16 percent of the rural primary arterials carried less than 2 percent of Class 9 trucks, and another 16 percent carried more than 12 percent of Class 9 trucks. This level of variation is fairly typical for most States. Figure 1 illustrates the cumulative Equivalent Single-Axle Loads (ESALs) that a roadway would experience under these three different assumptions.[2] The only difference in the three estimates shown in figure 1 are the Class 9 truck percentages. For a 20-year pavement life, an error of roughly 2.4 million ESALs would occur if the State average were used rather than the "true" percentage for a road that had Class 9 truck percentages — one standard deviation from the mean value.

If LTPP used the "average" value for a test section that experienced a high loading rate (in the example above, this would happen on 15 out of every 100 LTPP test sites), the research results would conclude that the pavement was exhibiting much better performance than it really was. Pavement designs based on these faulty conclusions would result in premature pavement failures.

Weights

Truck volumes are not the only source of loading variation. Legal weights for specific truck configurations vary from State to State. This results in very different loading characteristics for individual truck types. In addition, the percentage of trucks that are fully loaded can change dramatically from site to site, and even from one direction to another.

Table 1 shows how varied traffic characteristics can be among LTPP sites. Three common vehicle classes are shown. The effects of Rhode Island's much higher weight laws are obvious. However, even within a State, considerable differences exist among many of the loading patterns.

These loading differences can compound the errors caused by using the wrong vehicle classification percentages. The ESAL loading rates per vehicle in figure 1 are based on a statewide average. If the loading rate at the LTPP test site is comparable to Minnesota site 3014 (which exhibits very heavy Class 9 trucks) and the site exhibits a Class 9 truck percentage equal to one standard deviation above the mean statewide average, the error resulting from the use of the statewide average is almost 13 million ESALs after 20 years. The growth in this error over time can be seen in figure 2.

Accurately Measuring Conditions

As illustrated by the examples, the traffic data submitted to LTPP show that the loading conditions found at LTPP test sites cover a range of loading conditions. Some sites have high truck volumes, but a large percentage of those trucks are very light (either empty or carrying light, bulky cargo). Other sites have high truck volumes of very heavy trucks. Still other sites have fairly low volumes of very heavy trucks, producing much higher loading conditions than might be expected for a low-volume road. Finally, some roads experience little loading whatsoever. The only way that LTPP engineers can accurately determine how well a State's pavement designs are functioning is if these different loading conditions are accurately measured at each site. Without this information, the results obtained from LTPP research are subject to significant uncertainty, and they have a high probability of misrepresenting the true performance of test pavements.

TABLE 1. ESAL loadings per vehicle by vehicle class at six LTPP sties.

CLASS	MN 1029	MN 1023	MN 4054	MN 3014	WA 6020	RI 7401
6	0.782	0.750	0.563	0.599	0.187	4.474
9	1.332	1.788	1.690	2.669	0.331	8.193
11	0.389	0.429	1.562	2.094	1.002	3.706

Foot Notes:

[1] *Traffic Forecasting for Pavement Design* (FHWA-TS-86-225), March 1988.

[2] These estimates are based on an Annual Average Daily Traffic of 5,000 vehicles per day, and truck percentages of 3.44 for all two-axle truck categories, 0.71 for all three-axle truck categories, 0.07 for all four-axle truck categories, and 0.18 for all non-FHWA Class 9 five-axle and larger truck categories. All other vehicles are assumed to be passengers cars. ESALs per truck values are 0.11, 0.47, 0.66, and 1.63 for the above catergories, respectively. The FHWA Class 9 vehicles are assumed to be 0.98 ESALs per vehicle.

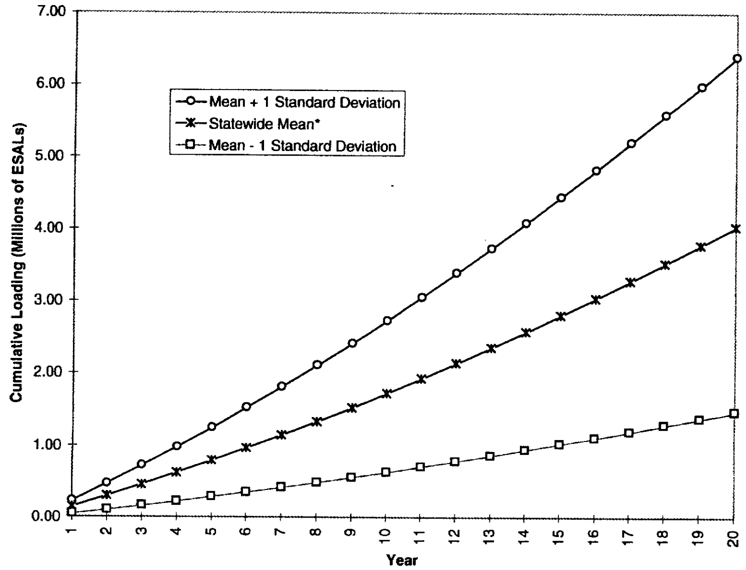


FIGURE 1. Cumulative ESAL loading as a function of truck percentage over time.

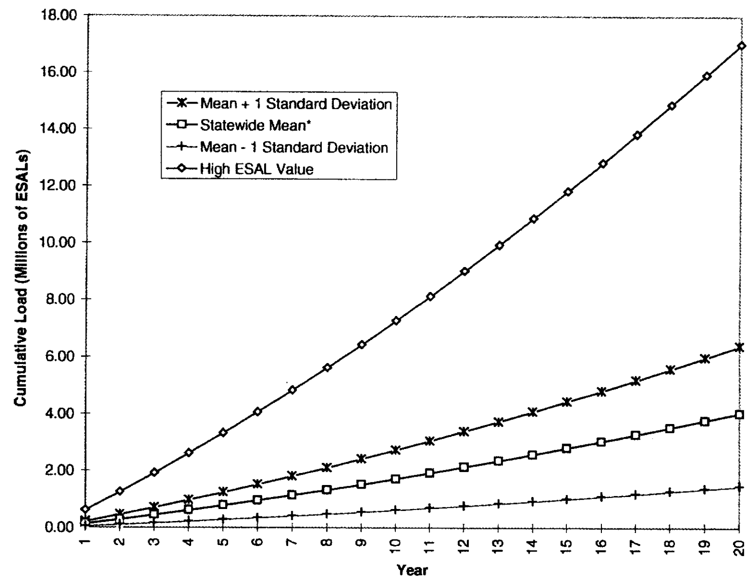


FIGURE 2. Effect of load and vehicle percentage on design ESALs.

* Mean value for the percentage by vehicle type for rural primary arteries from Washington State.

Researcher: This study was performed by Law PCS, 12104 Indian Creek Court, Suite A, Beltsville, MD 20705 and the Washington State Transportation Center, University of Washington, University District Building, 1107 NE 45th Street, Suite 535, Seattle, WA 98105-4631. Contract No. DTFH61-97-C-00002.

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Key Words: LTPP traffic, ESAL estimation, site-specific traffic.

SITE CONDITIONS

Pavement projects start out with a given set of site conditions, including traffic, climate, and subgrade/foundation. LTPP data analyses have shown that each of these site conditions affects pavement performance. While these conditions cannot be controlled, they always should be considered. In critical situations, the pavement design features should be selected to mitigate the adverse effects of site conditions on performance. The following key findings from several LTPP site conditions analyses are grouped into three areas: traffic, climate, and subgrade/foundation.

Traffic

1. **Report No. FHWA-RD-00-054**
Information on cumulative truck axle loads plays an important role in pavement design and performance analysis. It is especially crucial for mechanistic design methods and load-related distress prediction models. A comprehensive traffic load spectra projection methodology was developed using a corridor-assignment model and evaluated at 12 LTPP test sections. Initial results indicate that the proposed methodology can provide feasible traffic load projections.

2. **Report No. FHWA-RD-00-054**
The new traffic load projection methodology provides a way to predict annual axle load spectra. These are the frequency distributions of axle weight of a given axle type into weight ranges for:
   - All in-service years of a roadway segment.
   - Single, tandem, and tridem axles.
   - All trucks combined (Federal Highway Administration (FHWA) vehicle classes 4 through 13).

   The cumulative axle load spectra can be obtained by summing the annual axle load spectra to the year of interest.

3. **Report No. FHWA-RD-03-094**
Annual axle load spectra projected by the traffic load projection methodology for all in-service years up to 1998 were concluded to be reasonable (i.e., falling into expected ranges) for the majority (558 or 63 percent) of the 890 LTPP traffic sites. The traffic load spectra projected for the remaining 332 (37 percent) of traffic sites were considered unreliable because of inadequate or missing data collected at those sites.

4. **Report No. FHWA-RD-03-094**
The LTPP Pavement Loading Guide (PLG) was developed to overcome the difficulty of estimating traffic loads for the remaining 332 (37 percent) of the 890 LTPP sites. The document contains guidelines for the development of the PLG along with two examples using the PLG to obtain traffic load projections for LTPP sites without site-specific truck class and/or axle load data.

5. **Report No. NCHRP 20-50(5)**

In pavement design, the vehicle class distribution and the axle load spectrum cannot be assumed using a default or single load distribution for either the roadway functional class or a region.

6. **Report No. NCHRP 20-50(5)**
To make predictions that can be used with confidence, research quality traffic survey data of at least 5 years is recommended, which should include accurately measured vehicle classes, number of axle loads, and load configurations for a given roadway segment.

7. **General Traffic Pattern Findings**
Report No. FHWA-RD-03-094
Based on the 558 LTPP traffic sites with reasonable axle load projection results, general traffic pattern findings obtained are summarized as follows:
    - The leading 4 traffic load contributors are 5-axle single trailer trucks (FHWA vehicle class 9), 2-axle-6-tire single unit trucks (class 5), 3-axle single unit trucks (class 6), and 4-axle or fewer single trailer trucks (class 8). These four vehicle classes comprise 90 percent of the vehicles projected.
    - The projected percentages of all vehicles contributed by 5-axle single trailer trucks and 2-axle-6-tire single unit trucks are listed, respectively, for four roadway functional classes:
        - For urban principal interstates: 50 percent and 25 percent, respectively.
        - For urban principal freeways and expressways: 45 percent and 20 percent, respectively.
        - For rural principal interstates: 65 percent and 10 percent, respectively.
        - For rural principal freeways and expressways: 50 percent and 20 percent, respectively.
    - The minimum average daily traffic truck volume ranges from 30 trucks per day for a site located on a rural minor arterial highway to 6,310 trucks per day on a site located on an urban interstate highway. Between 1994 and 1998, the projected mean annual growth rate in truck volumes was:
        - For urban freeways and expressways: 6.5 percent.
        - For rural interstates: 4.6 percent.
        - For rural minor arterial highways: 3 percent.

8. **Vehicle Characteristics**
Report No. FHWA-RD-00-054
    - As of 1998, the nearly exclusive use of radial truck tires was observed at all LTPP sites. By comparison, 74 percent of all truck tires were radials in 1988.
    - The use of air suspension in trucks has increased. As of 1998, about 80 percent of all new truck tractors and about 60 to 70 percent of all new semi-trailers were equipped with air suspension.
    - Compared to bias ply tires, radial tires operate at higher tire pressures and, thus, generate more sharply defined imprints on pavements, which represent more concentrated loads.
    - Compared to the traditional spring-leaf suspension, air suspensions are considered to generate lower dynamic pavement loads. However, air suspensions result in a common high dynamic load frequency regardless of load magnitude. The spatial concentration of traffic loads leads to accelerated localized pavement damage.

Climate

1. **Climatic Effects on Pavement Performance**
Report No. FHWA-RD-01-167
    - In the SPS-2 experiment, the highest transverse cracking was observed in the slabs built in the dry no-freeze climates, followed by the wet-freeze climates, and then by the dry-freeze climates. The slabs built in the wet nofreeze climates have the lowest transverse cracking. The data support similar findings from earlier studies that, in drier climates (the western United States) where high thermal gradients exist, it is important to design for resistance to transverse cracking (shorter joint spacing minimizes the adverse effect of climate).
    - The largest longitudinal cracking lengths of SPS-2 sections occurred in the dry no-freeze climates, followed by the dry-freeze climates, and then by the wet-freeze climates. The lowest longitudinal cracking lengths were observed in those sections built in the wet no-freeze climates.

2. **Estimating Climatic Parameters Using Virtual Weather Stations Data**
Report No. FHWA-RD-03-092
    - The daily, monthly, and yearly LTPP Virtual Weather Station (VWS) climatic estimates obtained by a newly developed

model were found to be reasonably accurate for locations across North America. The climatic conditions (including air temperature, precipitation, humidity, freezing index, and wind speed) for 880 SPS and GPS pavement sections are estimated using data from as many as 5 nearby national weather stations. These VWS estimates are compared to onsite data for the same time period measured by the Seasonal Monitoring Program (SMP) at 63 GPS and SPS sections and by Automatic Weather Stations at 35 SPS test sections. Results of this comparison have verified that the model for developing VWS estimates can be a useful tool to predict climatic conditions.

- The LTPP VWS climatic estimates also were found to compare well to the National Climatic Data Center's (NCDC) measurements. These data were collected from 1994 through 1996 for the NCDC Cooperative Program; they covered 8,000 weather stations scattered over 5,347 NCDC sites throughout the United States.
- A difference in elevation between a project site and the nearby weather station(s) of more than 250 meters (m) (825 feet (ft)) significantly affects the climatic estimates. In this case, temperatures must be corrected to reduce the bias of the estimate. A model was developed for correcting the maximum temperature for elevation difference.
- Within a range of 60 kilometers (km) (37.5 miles), the distance of the contributing weather stations from a project site does not affect the VWS estimates at any project site.

3. **Variability of Climatic Parameters**
   FHWA-RD-03-092
   Significant year-to-year variability was observed in climatic data, an important factor for pavement design procedures. The yearto- year variability of annual precipitation is 21 percent; and of the freezing index, 34 percent. On average, the year-to-year variability of monthly temperature data is 6 percent.

Subgrade/Foundation

1. **Environmental Effects in the Absence of Heavy Load**
   Report No. FHWA-RD-02-087
   It is very important to study the effects of environmental factors such as climate and subgrade on the performance of flexible and rigid pavement with a reduced number of heavy axle loads. The SPS-8 experiment is designed to emphasize the effects of siterelated factors (temperature, precipitation, and subgrade) and structural factors (pavement type and layer thickness) on flexible and rigid pavements with no more than 10,000 18-kip equivalent singleaxle loads (ESALs) per year in the study lane. The SPS-8 experiment can be considered as an extension of SPS-1 (new flexible pavements) and SPS-2 (new rigid pavements) with limited traffic effects.

   - Temperature and Precipitation

     For SPS-8 AC sections, the most prevalent early distress is longitudinal cracking outside the wheel path. The distress is most commonly observed for sections built in the wetfreeze climates and for sections on an active subgrade (frost-susceptible or swelling soils due to freeze-thaw cycles). Fatigue, longitudinal cracking in the wheel path, and transverse cracking are present on just a few sections. The mean rut depths for all AC sections are below 6 millimeters (mm) (0.24 inches).

   - Subgrade

     - Pavements (flexible or rigid) constructed on active subgrade have the highest mean initial International Roughness Index (IRI) values and slopes (the smoothness rate of change over time), followed by pavements constructed on fine subgrade, and coarse subgrade. The data support a similar finding from previous studies that a good working platform (specifically, stabilized base and granular subgrade or embankment) contributed to a smoother pavement construction.
     - Initial IRI values for the SPS-8 test sections show that flexible pavements were constructed to be smoother than the rigid pavements. The analysis of IRI slopes indicates that the subgrade is the most important factor for flexible sections, while precipitation appears to be the most important factor for rigid sections.

   - Pavement Type and Layer Thickness

     - The SPS-8 flexible pavements with thin (102-mm (4-inch)) AC surface layers were found to be smoother than the sections with thick (178-mm (7-inch)) AC layers. Similarly, the SPS-8 rigid pavements with thin (203-mm (8-inch)) concrete slabs were constructed to be smoother than the sections with thick (279-mm (11-inch)) concrete slabs. This seems to contradict the general idea that thicker surface layers can generate smoother pavements.Further investigations should be conducted.
     - A few of the SPS-8 PCC sections have very limited transverse cracking and joint faulting. The mean joint faulting

on all PCC sections is insignificant, i.e., below 0.4 mm (0.02 inches). However, these observations are based on 8 years of data (the oldest SPS-8 test section was 8 years old as of June 2001), which is early in terms of pavement life.

- Comparisons of SPS-1, -2, and -8 Test Sections
  - As expected, traffic loading is much heavier on SPS-1 and SPS-2 than on SPS-8 sites. As of June 2001, the estimated accumulated ESALs on SPS-1 sites was about 1.46 million, compared to 0.043 million ESALs on SPS-8 AC sites. Similarly, SPS-2 sites had accumulated 4.77 million ESALs, compared to 0.23 million ESALs on SPS-8 PCC sections.
  - The average IRI slopes (the smoothness rate of change over time) for both SPS-1 and SPS-2 sections are much higher than for the corresponding SPS-8 sections. The variability of mean IRI slopes is higher for PCC than for AC sections.
  - Overall, the much more heavily loaded SPS-1 and SPS-2 sections exhibit higher amounts of load-related distresses. Such distresses include AC rutting, AC fatigue cracking, JPCP joint faulting, and JPCP transverse cracking. However, the non-load-related distresses including AC transverse cracking and non-wheel path longitudinal cracking are similar for SPS-1, SPS-2, and SPS-8.

2. **Moisture Contents**
   Report No. FHWA-RD-99-115
   The Time Domain Reflectometry (TDR) technique measures the dielectric constant of soils in the LTPP SMP. This constant can be used to compute the in-situ moisture content of unbound base and subgrade materials. This study was intended to develop procedures to produce good estimates of in-situ gravimetric moisture content using the TDR traces in the LTPP database.

   - In-situ gravimetric moisture content of unbound base and subgrade materials can be determined using a two-step procedure:
     - Volumetric moisture content of unbound base and subgrade materials is determined using four proposed models based on LTPP TDR traces and necessary material properties.
     - In-situ gravimetric moisture content is then determined using two newly developed methods based on volumetric moisture content.
   - The two-step procedure was further developed into a userinteractive computer program, MOISTER. The program is used to determine moisture content of unbound base and subgrade materials.

3. **Frost Penetration**
   Report No. FHWA-RD-99-088
   The bulk resistivity of a soil increases dramatically when the soil freezes. The electrical resistivity technique is used to measure the electrical resistance, which is the voltage drop divided by the current passing through a pavement depth, which is based on Ohm's law. Together with soil temperature measurements, the electrical resistivity (i.e., geometry-adjusted resistance) is used to estimate the depth of frost penetration beneath a pavement section.

   - A user-interactive computer program, FROST, was developed to facilitate the determination of frost penetration depth within a pavement structure by interpreting the electrical resistivity and soil temperature data collected at the SMP sections.
   - The moisture content of a soil determined by MOISTER (FHWA-RD-99-115) based on the TDR data can be used to confirm the freezing events as determined by FROST. The rationale is that the moisture content computed by TDR data does not include the frozen water (ice content). Hence, when a soil freezes, its TDR-computed moisture content drops because its unfrozen moisture content decreases.

Next

Bituminous Operations (part of Job Safety Analysis series) (11 min), PA DOT, 1993. Presents easy steps for work zone safety during bituminous operations. Simple training guide or refresher.

Bituminous Plant Inspection (2 Parts) (37 min), Washington State DOT. Gives basic information about bituminous plants, the materials in bituminous concrete, batch plant operations, and drum-mix plants.

Bituminous Surface Treatment (24 min), Washington State DOT, 1988. Covers the inspection process used to determine how much liquid asphalt and aggregate should be applied for new construction and rehabilitation.

Building the Notched Wedge Joint © (8 min), National Asphalt Pavement Assoication, 1998. Explores the reasons for superior performance of the notched wedge joint in pavement and its advantages during the construction process. Shows step-by-step procedures to follow in building the notched wedge joint.

Concrete Placement (17 min), Ken Heckman Productions, Inc. A simulated casting of a concrete pier shows the effects of concrete slump and vibration.

Detecting Flawed and Non-Standard Concrete (27 min), Virginia DOT Research Council. Discusses ways of examining concrete to determine its construction and durability, along with lab testing methods.

Field Testing Concrete (3 Parts) (34 min), Washington State DOT. Discusses testing methods to make sure the concrete delivered is what the designer has specified for a particular job. Included are explanations of equipment needed for concrete sampling and various test procedures.

Freeze-Thaw Testing, #30 (25 min), SHRP, 1994. Examines the causes of freeze-thaw damage in concrete and methods of prevention based on old and new techniques.

Fundamentals of Quality Concrete (17 min), Portland Cement Assoc. Provides an introduction to the five essential requirements of quality concrete.

Handling Hot Mix Asphalt (11 min), NAPA, 1993. A discussion of hot mix asphalt construction training and the types of training media offered by field personnel.

Hydrated Lime Key To Improved Asphalt Pavements (21 min), National Lime Association. Deals with the use of hydrated lime as an anti-stripping agent as well as a reducer of age hardening and low temperature cracking, leading to more durable pavements.

MN/Road—Building a Better Foundation for the Future (10 min), Minnesota DOT, 1995. Demonstrates how MN-Road, a Minnesota research program, uses state-of-the-art technology to test and improve current roadways to prepare them for the demands of 21st Century transportation.

Pavement Mixture Design (76 min), Minnesota DOT. A two-part program: Part 1 covers generic design procedures and Part 2 covers Minnesota design procedures and specifications.

Paving The Way for Tomorrow's Highways (16 min), SHRP. Discusses the highway of the future and its needs.

Prestressed Concrete Overlay on IH35 in Texas #13 (17 min), Portland Cement Association. This Research and Demonstration project was initiated by the Center for Transportation and Research at University of Texas to investigate the design and construction techniques that relate to prestressed concrete overlays.

Prevention Rutting: Strip Asphalt Pavement (25 min), USDOT/FHWA USDOT/FHWA. Describes what results from bad combinations of asphalt materials and how prevention rutting will reduce these problems and produce superior asphalt concrete.

Quality Control of Concrete on Site: Parts 1-4 (67 min), SHRP, 1994.

Resilient Modules Laboratory Tests Parts 1 & 2 (40 min), Washington State Transportation Center. A two-part video focusing on elastic modules and how it is measured in pavement surfaces.

Segregation Talk By Jay Hensley (1:36 hr). Jay Hensley gives a lecture on segregation — the non-uniform distribution of aggregates on sizes or specific gravities.

➤ **Smart Road** (7:54 min), Virginia DOT, 2000. This video documents high-tech safety research being done in Virginia on a specially-designed roadway that carries regular traffic. The project also includes bridge safety research.

➤ **Smoother Roads Playbook** (24:45 min), KDOT/FHWA, 2000. Eight practices used in Kansas to achieve smoothness with Portland cement concrete pavement are highlighted. Having a precise stringline is stressed with remarks by former NFL coach John Madden.

Solutions—America's Highways (4 min), ABC Network & American Coal Ash Assc., 1997. An excerpt from an ABC-World News tonight segment that discusses the use of high performance concrete (fly ash, micro-silica, and cement).

Texas Mobile Load Simulator (11 min), Texas DOT. Discusses pavement testing and design.

Thickness Design Manual (23 min), Asphalt Institute. Gives an overview of the Thickness Design Manual.

Truck Traffic: Weighing the Consequences (20 min), FHWA, 1990. Discusses the impact of truck traffic on pavements, how to enforce weigh stations and how truck impact research leads to changes in pavement design.

Borrow request submitted to LTAP

Urban Concrete Paving: Strength and Durability (15 min), Concrete Pavement Association. Discusses some advantages of paving with Portland cement concrete, as opposed to asphalt, in city applications such as streets.

BICYCLISTS & PEDESTRIANS

Bikes on Buses (6 min), Florida Bicycle/Pedestrian Commuter Center. Describes a transit program in Florida and equipment used to transport bicyclists and their bikes on buses.

Commute for Life (15 min), Colorado DOT, 1992. Shows how to implement bicycle commuting to work as a daily activity. Safety practices and laws are also mentioned.

Evaluating Conditions for Bicycling though Users' Perceptions and Operational Evaluations (1:10 hrs), Mid-America Transportation Center. A lecture by David Harkey describing the development and potential use of the bicycle compatibility index (BCI).

Pedestrian Safety—What You Can Do? (9 min), USDOT/FHWA. Explains basic safety measures to be taken on behalf of pedestrians. It stresses the three E's : engineering, education and enforcement.

Seattle's Bicycle Program (11 min), Seattle Engineering Department, no date. Describes Seattle's accomplishments in being a bicycle-friendly city through the use of a comprehensive trail system and on-street improvements for easier bicycle accessability.

See and Be Seen (9 min), AAA. Child safety rules for playing outside, precautionary measures to avoid being hit by a vehicle.

Trucks and Bicycles Sharing the Road (22 min.), American Trucking Assoc. Promotes skills for truckers and bicyclists for safe road sharing skills.

Trucks and Pedestrians—Keep It Between the Lines (18 min), American Trucking Association, 1993. This video explores safety concerns when pedestrians and trucks share the road.

➤ **Walk Our Children to School Day** (13:20 min), Thomas May Associates, Inc, 1999. This video is a compilation of several news segments highlighting Walk Our Children To School Day (October 6) in Alabama; parents were interviewed on the hazards they encountered on their walk to school.

WALK! (13 min), FHWA, OTA, HTA, 1996. This video is about making a more pedestrian-safe environment. It discusses how design problems put pedestrians at risk and stresses that communities need to take walkers into consideration when planning new projects.

Walking Through the Years (13 min), FHWA. Offers older adults (65+) helpful pedestrian-safety guidelines. Also includes five 30-second PSAs.

BRIDGES & CULVERTS: safety, inspection, & maintenance

Aesthetic Bridge Rails and Guardrails (8 min), FHWA. Shows how the beauty of historic and scenic areas can be maintained through the use of bridge rails and guardrails that blend in with the scenery.

Bridge Deck Overlays #28 (15 min), SHRP, 1994. Describes the concrete bridge overlay as a cost effective way to repair some kinds of bridge drainage.

Bridge Maintenance for Local Road Crews (14 min), Vermont Tech Transfer Ctr, 1994. Shows maintenance procedures local road crews can use to keep bridges in good condition.

Bridges Unbroken (20 min), Univ. of Maryland/ USDOT-FHWA, 1988. Discusses using ultrasound to inspect the condition of timber bridges. All aspects of inspection by ultrasound, from its inception at the University of Maryland at College Park to its application in the field, are covered.

Cleaning and Clearing of Bridges (13 min), FHWA, 1988. Describes the techniques used in the clearing and cleaning of bridges.

Cleaning of Lined Ditches, Culverts and Catch Basins (16 min), FHWA, 1985. Demonstrates how to clean lined ditches, culverts and catch basins.

Concrete Bridge Deck Repair (17 min), FHWA, 1988. Describes concrete bridge deck repair.

Concrete Bridge Protection, Repair and Rehabilitation (5 min), SHRP. Highlights the SHRP C-103 Field Guide, which deals with concrete removal, rapid bridge deck repair and protection, conventional bridge rehabilitation and deterioration due to chloride contamination.

Concrete Bridge Railings and The Modified Thrie Beam Guardrails and Cable Guardrails (38 min), FHWA. Three types of concrete barriers are discussed along with the advantages and performance of thrie beam barriers and cable guardrails.

Ideas That Make A Difference (12 min), Pennsylvania Transportation Center. Discusses saving time and energy in replacing pipes.

Impact of Truck Size and Weight on Highway Pavements and Bridges (30 min), FHWA. Covers axle loads, truck weight, load distribution and their relationship to pavement and bridge damage factors.

Borrow request submitted to LTAP

Inspeccion de Estructuras (Structures Inspection) (20 min), Texas T2 Center.

Introduction to Bridges (43 min), U. of Arkansas, 1993. An introduction to structural elements, loads and types of bridges commonly used in highway applications. Also briefly discusses how different bridges are built and how they behave.

Limpieza de Cuentas Y Reparacion de Derrumbes Menores (14 min), Texas T2 Center. (Remove Minor Slides and Clean Cut Ditches).

Maintain Drainage (10 min), Utah DOT, 1993. Describes the importance of maintaining roadside drainage to avoid major road deterioration.

Mantenimiento de Drenajes (12 min), Texas T2 Center. (Maintain Drainage).