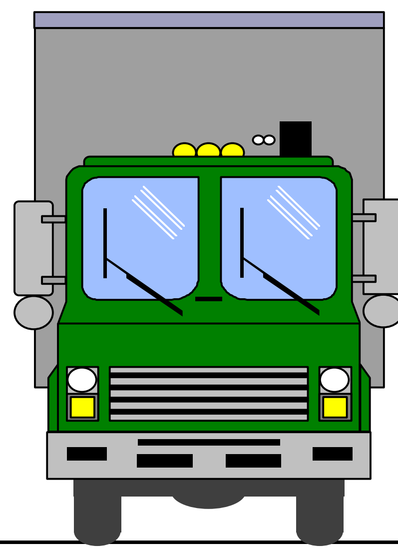
PART III

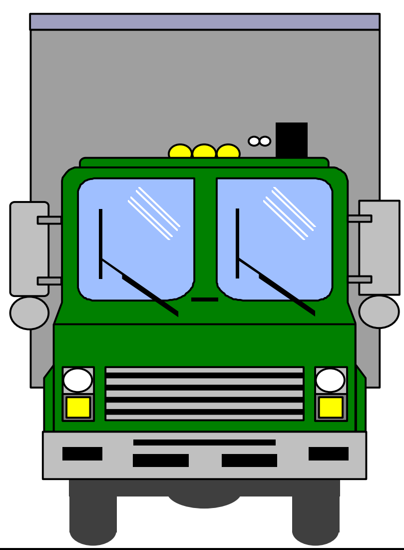
AGENCY COSTS:

-PAVEMENT PRESERVATION
-BRIDGE PROTECTION
-ROADWAY GEOMETRY



CHAPTER 5

Pavement



INTRODUCTION

The States spend billions of dollars each year to maintain their highway systems. The *1997 Status of the Nation's Surface Transportation System: Conditions and Performance Report to Congress* indicates that $470 billion will be required over the next 20 years just to maintain the condition of the system. Changes in truck size and weight (TS&W) policy, especially if they include new axle weight limits, could have a major impact on pavement quality and performance characteristics and, therefore, future investment requirements.

The condition and performance of a highway pavement is dependent on many factors including:

- Pavement structure, materials, and layer depth,
- Construction quality (including uniformity of pavement layers) and maintenance practices,
- Weather—amount of precipitation and freeze-thaw cycles,
- Subbase characteristics that underlie the pavement,
- Magnitude, spacing, and frequency of axle loads,
- Dynamic interaction between pavement conditions and vehicles—surface roughness and base strength and vehicle speed, number of tires per axle, tire pressures, and suspension characteristics.

The factors most relevant to a national level TS&W Study are the magnitude, spacing and frequency of axle loads. These factors along with information on surface roughness, base strength, pavement materials and structure, and weather conditions have been considered in this Study.

The elements of dynamic truck-pavement interaction have been the focus of considerable research in recent years (such as the Organization for Economic Cooperation and Development's "Dynamic Interaction Vehicle-Infrastructure Experiment"). However, current information on these dynamic interactions is inconclusive with respect to TS&W policy and their effects appear to be of secondary importance relative to static axle loads.

Axle load and frequency information have been estimated based on vehicle-miles-of-travel (VMT) information for various classes of highway vehicles, which includes the number of axles, from the *1997 Highway Cost Allocation (HCA) Study*. The *HCA Study* VMT estimates by vehicle class and weight group were modified for the alternative TS&W policies through the freight diversion analytical process (see Chapter 4).

Pavement and subbase data by highway section were taken from the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) database to which was added State specific weather and base thickness data. The HPMS data base includes detailed information on almost 100,000 sections of U.S. highways.

BASIC PRINCIPLES

TRUCK-PAVEMENT INTERACTION

In terms of vehicle-specific characteristics, pavement wear increases with axle weight, the number of axle loadings, and the spacing within axle groups, such as for tandem- or tridem-axle groups. Pavement impacts are also influenced by vehicle suspensions, tire pressure, and tire type. However, the analysis conducted for this Study does not quantify these secondary, vehicle-specific characteristics because they appear to be less important to pavement deterioration than pavement type and axle weight.

In general, highway pavements are stressed by axle and axle group loads directly in contact with the pavement rather than by gross vehicle weight (GVW). Of course, the GVW, along with the number and types of axles and the spacing between axles, determines the axle loads. Over time, the accumulated strains (the pavement deformation from all the axle loads) deteriorate the pavement condition, eventually resulting in cracking of both rigid and flexible pavements and permanent deformation or rutting in flexible pavements. Eventually, if the pavement is not routinely maintained, the axle loads, in combination with environmental effects, such as pavement moisture, accelerate cracking and deformation. (See box, below.)

PAVEMENT LIFE CONSUMPTION

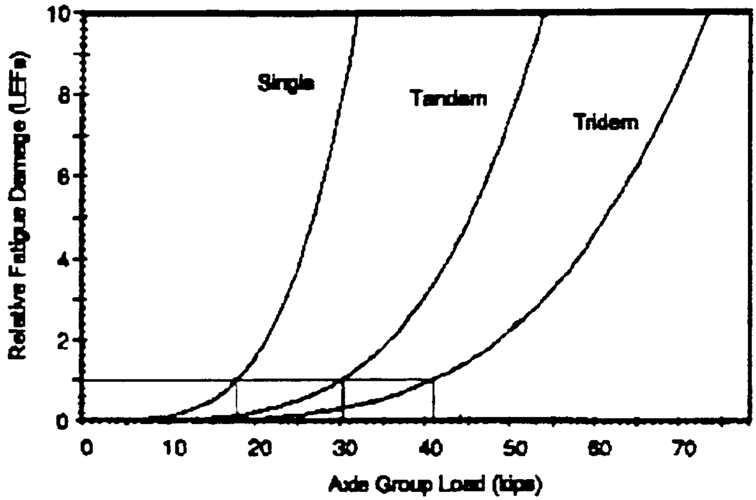
Proper pavement design relative to loading is a significant factor, which varies by highway system. The incremental effect on pavement deterioration increases sharply as the axle load increases. For example, according to the American Association of State Highway and Transportation Officials (AASHTO) pavement deterioration relationship—the fourth power relationship [(see "American Association of State Highway Officials Road Test" box, page 5-4)] —when a single axle is loaded to 20,000 pounds it will do more than 12 times the damage compared to an axle with a 10,000-pound load. However, the load carrying capacity of a pavement increases more rapidly (to a power higher than four) with increasing thickness than its deterioration due to heavier loads (see Exhibit 5-1).

PAVEMENT DETERIORATION - FATIGUE

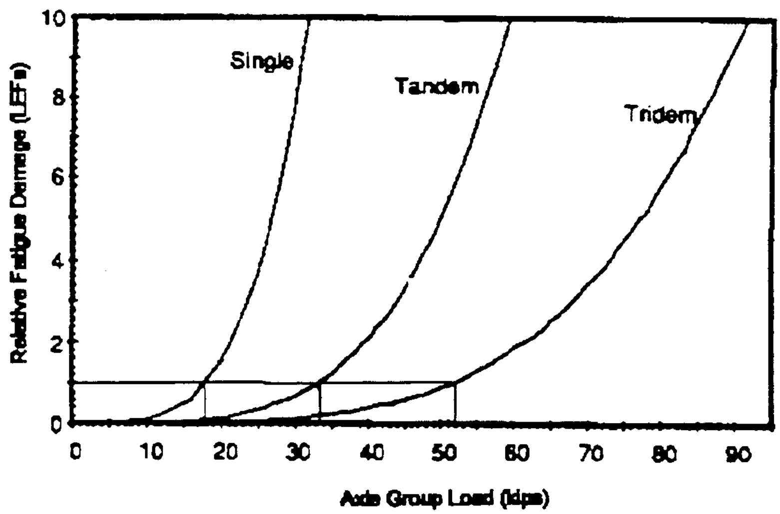
The break-up of pavements is usually caused by fatigue. Fatigue or fatigue cracking is caused by many repeated loadings and the heavier the loads the fewer the number of repetitions required to reach the same condition of cracking. It is possible, especially for a thin pavement, for one very heavy load to break up the pavement in the two wheel paths. To account for the effect of different axle weights, the relative amount of fatigue for an axle at a given weight is compared to that of a standard weight axle. Historically this standard axle has been a single-axle with dual tires and an 18,000-pound load.

EXHIBIT 5-1
RELATIVE FATIGUE VERSUS AXLE LOAD

FLEXIBLE PAVEMENT



RIGID PAVEMENT



Source: Gillespie, et. al. "Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance," NCHRP Report 353, Transportation Research Board, Washington, DC, 1993.

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AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS ROAD TEST

In the late 1950's the then American Association of State Highway Officials (now the American Association of State Highway and Transportation Officials) conducted pavement deterioration tests at Ottawa, Illinois. The measure of pavement deterioration used was the Present Serviceability Rating (PSR). The tests found that, with increasing axle load, pavements deteriorated at a rate that was roughly equivalent to the weight increase raised to the fourth power. It is important to note that all elements of pavement deterioration, such as cracking, rutting, and ride quality, were combined into the PSR for which the "fourth power" relationship was derived.

Adding one or two axles to a single axle to make a tandem- or tridem-axle group allows truck loads to be increased without increasing pavement damage. These axle groups reduce pavement consumption by spreading the load along more of the pavement. This effect is more significant for flexible than for rigid pavements (see "Flexible versus Rigid Pavements" box, right), although the difference is not large (see Exhibit 5-1).

The spread between two consecutive axles in a tandem- or tridem-axle group also affects pavement life or performance; the greater the spread the more each axle in a group acts as a single axle. Spreading axles within a group increases the fatigue damage in flexible pavements. Rigid pavements are affected differently by axle spread. Over short distances, rigid pavements act like bridges, and consequently, pavement damage is reduced by spreading axles. Exhibit 5-2 through Exhibit 5-4 compare the relative pavement consumption of those axle groups and truck configurations evaluated during the Study if they were used at the maximum allowable weight (see "Truck Operating Weights" box, page 5-6) all the time. These comparisons are based on the effects of the axle groups and their loads relative to a

FLEXIBLE VERSUS RIGID PAVEMENTS

Hard surfaced pavements are either flexible or rigid. Flexible pavements are surfaced with bituminous (or asphalt) materials. The total pavement structure "bends" or "deflects" in response to a load. Also, a flexible pavement structure is usually composed of several layers that absorb most of the deflection. Rigid pavements are made from portland cement concrete (PCC) and are substantially "stiffer" than flexible pavements. Some PCC pavements have reinforcing steel to give them strength in tension to resist expansion due to warm temperatures and to reduce cracking under repeated loading and, consequently the number of joints required.

Only 11 percent of all hard surfaced highways have rigid or composite pavements (rigid pavements with flexible overlays). The remaining have flexible pavements. Flexible pavements are expected to serve from 10 years to 15 years. In contrast, rigid pavements may serve up to 30 years. However, when a flexible pavement requires major rehabilitation, the work is generally less expensive and quicker to perform than for rigid pavements.

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18,000-pound single axle load. These relative effects are expressed in load equivalency factors (LEFs), which may be defined as the number of repetitions of a reference load and axle combination (such as the 18,000-pound single axle) that is equivalent in pavement life consumption to one application of the load and axle configuration in question. LEFs are useful in distilling the effects of different vehicle types into a single measure for comparison purposes. However, actual LEFs vary by pavement type and distress type.

Exhibit 5-2 shows theoretical LEFs for three of the more significant pavement distress types by axle group and weight. The rigid and flexible pavement LEFs for fatigue were interpolated from Exhibit 5-1. These theoretical LEFs have application here for discussion purposes. They should not be applied in any specific situation. The LEF values shown in Exhibit 5-1 and Exhibit 5-2 were derived from mechanistic pavement damage models and not from empirical data. Given this, they do not reflect environmental factors or the interactions of axle loads with environmental factors.

EXHIBIT 5-2
THEORETICAL LOAD EQUIVALENCY FACTORS OF VARIOUS AXLE GROUPS AND LOADS FOR MAJOR TYPES OF RIGID AND FLEXIBLE PAVEMENT DISTRESS (BASED ON 18,000-POUND SINGLE AXLE WITH DUAL TIRES)

Axle Group	Load (pounds)	Load Equivalency Factors		
		Rigid Pavement Fatigue (10-inch thickness)	Flexible Pavement	
			Fatigue	Rutting
Steering Axle Single tires	12,000	0.6	1.4	1.3
	20,000	3.1	4.0	2.2
Single Axle Dual tires	17,000 (STAA double)	0.9	0.9	0.9
	20,000	1.6	1.5	1.1
Tandem Axle	34,000	1.1	1.6	1.9
Spread Tandem-Axle (10-foot Spread)	40,000	1.4	3.0	2.2
Tridem-Axle (9-foot spread)	44,000	0.6	1.4	2.4
	51,000	1.0	2.5	2.8

Source: Gillespie, et. al. "Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance," NCHRP Report 353, Transportation Research Board, Washington, D.C., 1993

Truck Operating Weights

If all trucks operated at their maximum allowed weights, one could easily evaluate relative pavement impacts. However, truck weight data gathered by the use of weigh-in-motion equipment show that all truck configurations operate at gross vehicle weights (GVWs) spanning a broad range, including weights above their specified maximum limits. (Much of the operations above maximum limits occur under overweight permits.) The percentage of trucks operating at weights near the maximum GVW limit is no more than 25 percent to 30 percent. Further, combination trucks operate empty at least 10 percent of the time, and those used in dedicated bulk hauls are generally empty 50 percent of the time. Finally, all trucks often operate with partial loads. The vehicle-miles-of-travel estimation process described in Chapter 4 accounts for these truck operating weight patterns.

To properly account for the differences in axle weights, all axle weights are converted to their LEFs, which depend on the type of pavement and pavement distress being considered. LEFs also depend on the number of axles in the group and how widely they are spread.

These LEFs are summed for the axle groups on each truck configuration and shown in Exhibit 5-3. Exhibit 5-2 clearly shows the relative impact of a 12,000-pound versus 20,000-pound weight limit for a steering axle. This difference is reflected in Exhibit 5-3 in the LEFs for single-unit trucks (SUTs) versus combination trucks. Further, the 7,000-pound difference between a 44,000-pound and 51,000-pound tridem-axle weight limit results in 80 percent more pavement fatigue. Many of the combination trucks have LEFs lower than those for SUTs. Further, the four-axle truck has lower LEFs than the three-axle truck, and this is at a relatively low 54,000-pound GVW for the three-axle truck. In several jurisdictions, three-axle dump trucks operate at limits up to 65,000 pounds or more.

Two sets of LEFs are shown in Exhibit 5-3 for the seven-axle triple combination, one for use in less-than-truckload (LTL) operations with Surface Transportation Assistance Act (STAA) doubles and one for use in truckload (TL) operations (which would be attractive if there were no long doubles available for TL freight). The first set assumes 17,000-pound single axles and the second, 20,000-pound axles. This 3,000-pound difference in axle weights increases rigid pavement fatigue by 70 percent, flexible pavement fatigue by 53 percent, and flexible pavement rutting by 18 percent.

The relative impact of SUTs versus combination trucks is more starkly shown in Exhibit 5-4. This exhibit gives the LEFs for a given configuration carrying 100,000 pounds of payload. The number of trucks required to carry this payload ranges from one for the nine-axle turnpike double (TPD) to over three for the three-axle SUT.

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EXHIBIT 5-3

THEORETICAL LOAD EQUIVALENCY FACTORS FOR STUDY VEHICLE CONFIGURATIONS MAJOR TYPES OF RIGID AND FLEXIBLE PAVEMENT DISTRESS (BASED ON 18,000-POUND SINGLE AXLE WITH DUAL TIRES)

Configuration	Gross Vehicle Weight (pounds)	Number of Axles in Each Group (S=Steering Axle)	Load Equivalency Factors		
			Rigid Pavement Fatigue (10-inch thickness)	Flexible Pavement (5-inch wearing surface)	
				Fatigue	Rutting
Three-Axle Single Unit Truck	54,000	S,2	4.2	5.6	4.1
Four-Axle Single Unit Truck	64,000	S,3	3.6	5.4	4.6
	71,000	S,3	4.1	6.5	5.0
Five-Axle Semitrailer	80,000	S,2,2	2.8	4.6	5.1
Five-Axle Semitrailer (10-foot Spread)	80,000	S,2,2 (spread)	3.1	6.0	5.4
Six-Axle Semitrailer	90,000	S,2,3	2.2	4.4	5.6
	97,000	S,2,3	2.7	5.5	6.0
STAA Double (five-axle)	80,000	S,1,1,1,1	4.2	5.0	4.9
B-Train Double (eight-axle)	124,000	S,2,3,2	3.3	6.0	6.5
	131,000	S,2,3,2	3.8	7.1	6.9
Rocky Mt.Double (seven-axle)	120,000	S,2,2,1,1	6.0	7.6	7.3
Turnpike Double (nine-axle)	148,000	S,2,2,2,2	5.0	7.8	7.3
Triple (seven-axle)	114,000 (LTL operation)*	S,1,1,1,1,1,1	6.0	6.8	6.7
	132,000 (TL operation)**	S,1,1,1,1,1,1	10.2	10.4	7.9

*LTL= Less-than-truckload
**TL=Truckload

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EXHIBIT 5-4
THEORETICAL LOAD EQUIVALENCY FACTORS PER 100,000 POUNDS OF PAYLOAD CARRIED BY STUDY VEHICLE CONFIGURATIONS
(BASED ON 18,000-POUND SINGLE AXLE WITH DUAL TIRES)

Configuration	Gross Vehicle Weight (pounds)	Empty Weight (pounds)	Payload Weight (pounds)	No. Of Vehicles per 100,000 pounds of payload	Load Equivalency Factors		
					Rigid Pavement Fatigue (10-inch thickness)	Flexible Pavement (5-inch wearing surface)	
						Fatigue	Rutting
Three-Axle Single Unit Truck	54,000	22,600	31,400	3.18	13.4	17.8	13.0
Four-Axle Single Unit Truck	64,000	26,400	37,600	2.66	9.6	14.4	12.2
	71,000	26,400	44,600	2.24	9.2	14.6	11.2
Five-Axle Semitrailer	80,000	30,500	49,500	2.02	5.7	9.3	10.3
Five-Axle Semitrailer (10-foot Spread)	80,000	30,500	49,500	2.02	6.3	12.2	10.9
Six-Axle Semitrailer	90,000	31,500	58,500	1.71	3.8	7.5	9.6
	97,000	31,500	65,500	1.53	4.1	8.4	9.2
STAA Double (five-axle)	80,000	29,300	50,700	1.97	8.3	9.9	9.7
B-Train Double (eight-axle)	124,000	38,700	85,300	1.17	3.9	7.0	7.6
	131,000	38,700	92,300	1.08	4.1	7.7	7.5
Rocky Mt.Double (seven-axle)	120,000	43,000	77,000	1.30	7.8	9.9	9.5
Turnpike Double (nine-axle)	148,000	46,700	101,300	0.99	5.0	7.7	7.2
Triple (seven-axle)	114,000 (LTL operation)*	44,500	69,500	1.44	8.6	9.8	9.6
	132,000 (TL operation)**	44,500	87,500	1.14	11.6	11.8	9.0

*LTL= Less-than-truckload
**TL= Truckload

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Another perspective is to compare the relative pavement impacts of the five-axle semitrailer and a nine-axle TPD. To haul the same freight at the maximum allowable loads, a five-axle semitrailer would result in a 14 percent increase in rigid pavement fatigue, a 21 percent increase in flexible pavement fatigue, and a 43 percent increase in flexible pavement rutting. However, this would be a very isolated case. To realistically compare how pavement impacts change with changes in weight limits, it cannot be assumed that it is always cheaper to use the larger configurations, or that they always operate at their maximum allowable weights.

ANALYTICAL APPROACH

Alternative weights for current truck configurations were analyzed in terms of their interaction with highway infrastructure features. The configurations included were single-unit or straight trucks and single- and multitrailer truck combinations. Pavement types analyzed include flexible (asphaltic concrete) and rigid (portland cement concrete).

The methodology employed to assess the potential pavement impact of alternative TS&W policy scenarios on pavement life consumption involved two phases. The first phase included new research on tridem-axle impacts. Of particular interest was the relationship between axle loads, axle spacings and pavement deterioration. The goal was to develop optimum axle load and spacing criteria that also took into account potential bridge impacts.

The second phase included the development of pavement impact cost estimates based on the pavement cost model used for the *HCA Study* analysis. A number of revisions were made to that model to make it more sensitive to TS&W policy options.

TRIDEM-AXLE IMPACT RESEARCH

In the United States, the allowable load on a group of three axles connected through a common suspension system (a tridem-axle) is determined by the Federal Bridge Formula (FBF) rather than a limit set by law (or regulation). In Europe, Canada, Mexico, and other jurisdictions, tridem axles are given a unique load limit in the same way the United States specifies unique single- and tandem-axle limits without the use of a bridge formula. This is not to say that these unique tridem limits are not bridge-related. In Canada, for example, the tridem limits vary as a function of spacing, based on bridge loading limitations—not pavement limitations.

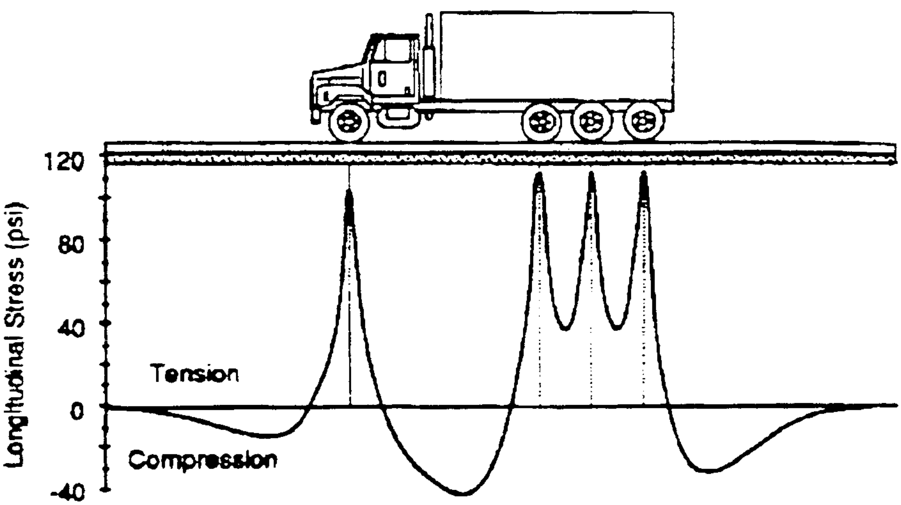
Tridem axles could be considered as a way to increase truck load capacity while reducing pavement damage (see "Use of Spread-Tandem versus Tridem Axle" box, page 5-10). There already has been a switch from three-axle to four-axle SUTs by many heavy bulk freight haulers, and as noted above, significant pavement cost savings may be possible. The 80,000-pound GVW limit poses a constraint on adding axles to five-axle combinations because, under the GVW limit, the extra axle would reduce the payload.

An evaluation of a specific limit for tridem groups was undertaken as the FBF is conservative for closely spaced axles. In contrast, it is liberal in the weight it allows for long multitrailer combinations. During the development of the truck configuration building blocks early in the Study, a 97,000-pound six-axle semitrailer combination was selected for evaluation, because at that weight a 40-foot container loaded to the ISO (International Standards Organization) maximum limit could be moved without requiring a permit on Interstate

USE OF SPREAD-TANDEM VERSUS TRIDEM AXLE

There is increasing use of wide-spread (up to 10 feet) "spread-tandem" axle groups, particularly in flatbed heavy haul operations. These axles are allowed to be loaded at single axle limits--20,000 pounds on each of the two axles as opposed to 34,000 pounds on a closed tandem. They offer two key benefits relative to five-axle tractor semitrailers combinations: (1) flexibility in load distribution, and (2) full achievement of the 80,000-pound gross vehicle weight cap, which is limited by the ability to distribute up to 12,000 pounds on the steering axle of a combination. But they do so with significant pavement costs. Their expanding use could be counteracted with a higher tridem-axle load to the benefit of pavements.

The diagram below shows why tridem-axles are more pavement friendly than split-tandem axles. As loads are moved from farther to closer distances, the stresses they apply to the pavement structure begin to overlap; they stop acting as separate loads. While maximum deflection of the pavement surface increases as axle spacing is reduced, maximum tensile stress at the underside of the surface layer will decrease. Tensile stress is a primary cause of fatigue cracking and can decrease as axle spacing is reduced. However, the net effect of changes in axle spacing is very complex and dependent on the nature--flexible versus rigid--of the pavement structure.



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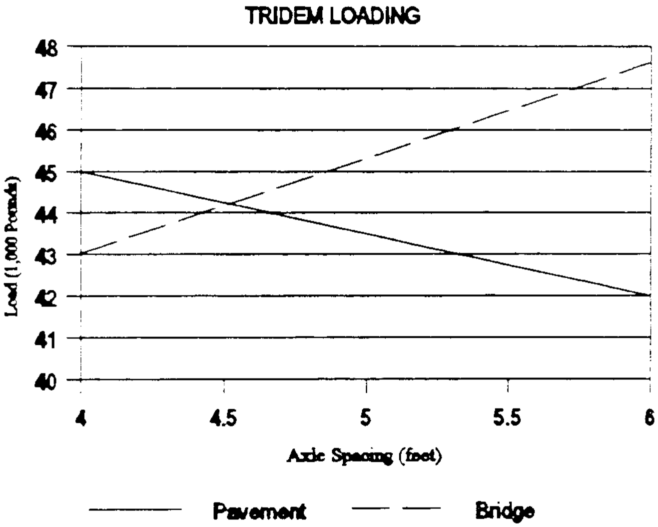
highways. Implicit in this is a 51,000-pound limit for the tridem-axle group. (See Chapter 3, North American Trade Scenario discussion.)

However, Study research into the optimum tridem-axle weight from both a pavement and a bridge perspective, found that the optimum limit was 44,000 pounds for a tridem axle with nine feet between the first and last axles in the group. If the axles were to be spread more than this, pavement fatigue would increase, while bridge stress would decrease. And conversely, if the nine feet were shortened, bridge stresses would increase, while pavement fatigue would decrease. As a result of the research both the 44,000-pound and the 51,000-pound limits were evaluated. (See "Tridem Axle Infrastructure" box, below.)

TRIDEM AXLE INFRASTRUCTURE IMPACTS

The complexity of the interactions of truck weights and dimensions on pavements and bridges is illustrated in the graph below. This graph shows that spreading the individual axles in the tridem-axle group increases pavement wear primarily through fatigue, but it decreases the maximum stresses in a simple bridge span by reducing the maximum stress at the midpoint of the span. It also shows that the optimal weight limit considering both pavement and bridge impacts for a tridem axle is 44,000 pounds when there is 4.5 feet between two adjacent axles. To spread the axles further would increase pavement wear beyond that of the present 34,000 pounds allowed on a tandem axle. To move the axles closer together would increase stresses in certain bridges beyond that allowed under the current bridge stress criteria.

Relative Pavement and Bridge Impacts
Tridem Axle



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THE NATIONAL PAVEMENT COST MODEL

The National Pavement Cost Model (NAPCOM) is used to estimate potential pavement impacts resulting from changes in the Nation's TS&W limits. NAPCOM is a complex simulation model developed for use in the 1982 Federal *HCA Study* and subsequently improved for use in the 1997 *HCA Study*. For these studies, the model was used to attribute pavement rehabilitation costs to specific groups of vehicles. The model is sensitive to different weight policies, depending on truck configuration, including the number of axles.

OVERVIEW

To estimate the impact of the various scenarios on pavement requirements, NAPCOM was applied to generate (1) lane-miles of failed pavement in the base case and (2) lane-miles of failed pavement under the test scenario conditions. In each case, lane-miles of failed pavement was translated into pavement costs. NAPCOM implements a 20-year life cycle analysis to generate the number of failed lane miles by functional class of highway and highway type. The improvement needs relate to a 20-year stream of traffic (from 2000 to 2020).

INPUT DATA

NAPCOM uses information about specific, representative highway sections supplied by the States through the FHWA's HPMS process. The HPMS includes approximately 100,000 records of pavement sections each of which includes detailed information on design characteristics, current condition of the pavement, and the traffic that uses that particular segment (current and 20-year projection).

NAPCOM uses the following information from HPMS: number of lanes, type of pavement, pavement thickness, current pavement condition, average daily traffic, percentage of trucks in the traffic stream, predicted 20-year traffic levels, climatic zone, and some rudimentary information about the pavement base. The HPMS data is supplemented with additional State-characteristic information, to include: freeze-thaw cycles, freezing index, average rainfall and thickness of base.

NAPCOM uses the following fleet data developed for the *HCA Study*: (1) annual VMT by vehicle class, highway functional class, and State; (2) operating weight distribution for each vehicle class on groups of highway types in groups of States; and (3) axle weights for the midpoint of each weight group for each vehicle class.

A different traffic loading was estimated for each TS&W policy scenario. This was done by starting with the VMT file created by the *HCA Study* and modifying it based on the new distribution of freight between truck and rail, from one truck configuration to another, and from one weight group to another for a given truck configuration (see Chapter 4). This produces a VMT file for each scenario stratified by truck configuration, weight group (5,000-pound increments), functional class of highway, and State.

PAVEMENT DETERIORATION MODELS

The NAPCOM relies on 11 pavement distress models to estimate how quickly

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traffic loadings will result in the requirement for a pavement restoration improvement. These models determine the expected pavement condition at the end of each year of analysis. They evaluate the following distresses on flexible pavements: (1) traffic-related Pavement Serviceability Rating (PSR) loss, (2) expansive-clay-related PSR loss, (3) fatigue cracking, (4) thermal cracking, (5) rutting, and (6) loss of skid resistance. Distresses considered for rigid pavements include: (1) traffic-related PSR loss, (2) faulting, (3) loss of skid resistance, (4) fatigue cracking, (5) spalling, and (6) soil-induced swelling and depression.

The NAPCOM distress models do not use AASHTO's Fourth Power Law for pavement load and deterioration. Rather, load relationships and exponential relationships for each of the types of distress have been estimated. For most of them, the exponent would be slightly less than four. The effect of load is not as great as the simple AASHTO road test relationship for loss of serviceability would indicate.

Cost Calculations

Of interest for this Study, the model provides the number of failed lane miles by highway type (flexible or rigid) and functional class of highway. The estimate of total failed lane miles by functional class of highway is combined with pavement rehabilitation unit cost figures by functional class of highway to create an estimate of the impact on pavement rehabilitation costs, all expressed in 1994 dollars.

ASSESSMENT OF SCENARIO IMPACTS

To properly measure the pavement impacts, each scenario result must be compared with those pavement costs that would be incurred without a change in truck weight policy, the base case (see Exhibit 5-5). The estimated cost to maintain the current pavement conditions for the year 2000 with no TS&W policy changes is $196 billion in pavement restoration costs over 20 years. A comparison of the relative pavement impacts of the scenarios reveals that the Triples Nationwide Scenario had the largest increase in pavement restoration costs. It had an impact of $58 million in costs over 20 years (0.03 percent of the base case).

The fact that these pavement impacts are very small should not be surprising as axle weight limits were not increased in any of the scenarios, except for the 44,000-pound and the 51,000-pound limits for the tridem-axle on the four-axle SUT, six-axle semitrailer, and eight-axle B-train configurations in the North American Trade Scenario. Further, this scenario, with the 44,000-pound tridem-axle weight limit, resulted in a net savings of $3.1 billion in pavement restoration costs (a 1.56 percent decrease) over 20 years. The North American Trade Scenario with the 51,000-pound tridem-axle weight limit would result in a savings over 20 years of $2.4 billion (a 1.25 percent decrease).

Exhibit 5-5
Scenario Pavement Impacts

Analytical Case		VMT (million)		Impacts ($million)	
		All Highway Vehicles	Heavy Trucks (3 or more axles)	20-Year Pavement Costs	Change from Base Case
1994		2,359,984	109,979	194,285	- 2,254
2000 Base Case		2,693,845	128,288	196,539	0
Scenarios					
Uniformity		2,697,908	132,351	195,873	- 666
North American Trade	44,000-pound tridem axle	2,680,228	114,671	193,475	- 3,064
	51,000-pound tridem axle	2,680,189	114,632	194,092	- 2,447
LCVs Nationwide		2,664,119	98,562	196,141	- 398
H.R. 551		2,693,868	128,311	196,541	2
Triples Nationwide		2,667,957	102,400	196,597	58

In terms of changes in heavy truck VMT (128,288 million for the base case), the Uniformity Scenario, which had the largest increase, increased heavy truck VMT by 4,063 million (3.2 percent). The LCVs Nationwide Scenario had the largest decrease 29,726 million (23.2 percent). Specific information on the pavement impacts for each scenario follows.

UNIFORMITY SCENARIO

One should note that, although this scenario had the largest increase in heavy truck VMT (4,063 million—3.2 percent), it had savings in pavement restoration costs of $666 million over 20 years (0.3 percent of the base case pavement restoration costs) (see Exhibit 5-5). This results from the significant shift of VMT to lower weight groups for all configurations but especially for combination vehicles.

At the most pavement-sensitive axle weights, this shift was as much as 5,000 pounds downward in GVW for semitrailer combinations and more for those truck configurations that typically operate above the 80,000-pound Federal maximum GVW limit. That is, the decrease in weight resulted in reduced axle loads that result in even greater decreases in pavement wear. The positive effect of decreased axle loads overwhelmed the negative effect of increased VMT.

NORTH AMERICAN TRADE SCENARIOS

These two scenarios, one based on a 51,000-pound tridem-axle weight limit and the other on a 44,000-pound weight limit, had the largest savings in pavement restoration costs. They had virtually the same change in heavy truck VMT, a 10.6 percent decrease (13,656 in absolute numbers for the 51,000-pound tridem axle weight limit and 13,617 for the 44,000-pound limit) and savings in pavement restoration costs over 20 years of $2,447 million for the 51,000-pound limit and $3,064 million for the 44,000-pound limit (see Exhibit 5-5). The configurations of significance in this scenario are the five-axle semitrailer which loses freight to the eight-axle B-train double combination. The changes in VMT for the five-axle semitrailer combination in both scenarios are a reduction of 70.0 percent and 73.5 percent for the 51,000-pound limit and 44,000-pound limit respectively, and for the B-train double-trailer combination a gain of 7,075 percent and 6,725 percent for the 51,000-pound and 44,000-pound limits respectively (the base case VMT for this configuration is 683 million).

Also significant are the differences in LEFs for these three configurations. Exhibit 5-3 shows that their LEFs are comparable, but Exhibit 5-4 shows that in terms of payload carried, the six-axle semitrailer and eight-axle B-train double have much lower theoretical LEFs than the five-axle semitrailer combination. For example, based on a 51,000-pound tridem weight, these LEFs are 4.1, 8.4, and 9.2 for the six-axle semitrailer combination; 4.1, 7.7, and 7.2 for the eight-axle B-train combination; versus 5.7, 9.3 and 10.3 for the five-axle semitrailer combination. These theoretical differences are reflected in the more precisely estimated pavement impacts, which are estimated based on actual truck loads and pavements.

LONGER COMBINATION VEHICLES NATIONWIDE SCENARIO

This scenario had a decrease in heavy truck VMT of 29,726 million (23.2 percent) and a savings in pavement restoration costs of $398 million over 20 years (0.2 percent of the base case pavement restoration costs) (see Exhibit 5-5). The configurations of significance in this scenario are the five-axle semitrailer which loses freight to the nine-axle TPD and the five-axle STAA double which loses freight to the seven-axle triple. The changes in VMT for the five-axle semitrailer combination are a loss of 76.6 percent and for the TPD a gain of 42,500 percent (the base case VMT for this configuration is 76 million). The VMT change for the STAA double-trailer combination is a loss of 82 percent, and the change for the triple-trailer combination is a gain of

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4,650 percent (the base case VMT for the triple is 126 million).

Exhibit 5-4 shows that a TPD has appreciably fewer LEFs in terms of payload carried than a five-axle semitrailer, that is, 5.0, 7.7, and 7.2 versus 5.7, 9.3, and 10.3 respectively. This, along with the reduction in overall VMT, would account for most of the savings in pavement rehabilitation costs for this scenario. The "payload" LEFs for the STAA double and triple combinations (when used in LTL operations) are virtually the same. Consequently, this shift in freight from the double- to the triple-trailer combination has little effect on pavement impact.

H.R. 551 SCENARIO

This scenario had no change in weight limits and virtually no impact on heavy truck VMT (an increase of 23 million—0.02 percent) and consequently, virtually no impact on pavement restoration costs (see Exhibit 5-5).

TRIPLES NATIONWIDE SCENARIO

This scenario had a decrease in heavy truck VMT of 25,900 million (20.2 percent) and an increase in pavement restoration costs of $58 million over 20 years (0.03 percent of the base case pavement restoration costs) (see Exhibit 5-5). The configurations of significance in this scenario are the five-axle semitrailer and five-axle STAA double-trailer combination both of which experience freight shifts to the triple-trailer combination. As the triple-trailer combination is the one with the highest weight limit and cubic capacity in this scenario, it attracts freight from the semitrailer combination as well as from the STAA double-trailer combination. The VMT change for the STAA double-trailer combination is a loss of 82.1 percent and for the five-axle semitrailer a loss of 72.1 percent. The change for the triple-trailer combination is a gain of 31,400 percent (the base case VMT for the triple is 126 million).

The effect of the triple-trailer combination in this scenario is very different from its effect in the LCVs Nationwide Scenario. In that scenario it had virtually no effect in terms of total VMT as it only attracted freight (and VMT) from the STAA double-trailer combination. However, in this scenario it also attracts freight from the five-axle semitrailer combination. In this use, it can be expected to operate at GVWs up to 132,000 pounds with up to 20,000 pounds on its single axles with dual tires. Exhibit 5-2 shows that the LEFs are much higher for a single axle loaded to 20,000 pounds rather than 17,000 pounds (1.6 versus 0.9). This lower weight would be expected for its use in LTL operations because STAA doubles are limited to basically 17,000 pounds by the 80,000-pound GVW limit on the five-axle STAA double. Again, these theoretical differences in LEFs are reflected in the more precisely estimated pavement impacts, which are based on actual truck loads and pavements.

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