The Use of Site-Specific Truck Traffic To Evaluate the Performance of Surface-Treated Pavements

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A comprehensive procedure is described that can be used to examine the effects of unique truck traffic on surface-treated pavements. Detailed regional and site-specific truck traffic information was collected, and a computer program was modified to model pavement performance under baseline and special-use truck traffic conditions. The program estimated various types of pavement distress and provided a basis for the selection of appropriate pavement maintenance strategies. The analysis procedure began with oil and gas field activities and was expanded to include several other load-intensive, special-use commodities such as timber, grain, cattle, cotton, produce, sand and gravel, and limestone. The unique traffic characteristics of these vehicles were investigated over a 3-year period.

A report on low-volume roads in oil-producing areas in Texas was presented at the Third International Conference on Low-Volume Roads (*1*). A pavement analysis procedure was developed in which life-cycle costs for thin-surface-treated pavements could be computed. Although the estimates developed in the first study of oil field damage provided site-specific information for assessing the impact of oil field traffic on low-volume, light-duty pavements, the analysis procedure was found to be applicable to other special-use industries.

Special-use industries generate traffic that originates or ends on low-volume roads. This traffic is often atypical in terms of travel patterns, trip lengths, truck configuration, and axle loads. The travel patterns of these users tend to be cyclical in nature; the same trip is made, in some cases, several times in a typical day. Trip lengths are relatively short, usually less than 100 mi. The origin and destination may remain the same month after month, but eventually either the location of the origin or the destination changes after a period of time. Axle loads are in many cases greater than normally expected, although they generally are not well documented. Trips generated by these special-use activity centers eventually pose problems in the planning, design, and maintenance of the highways that serve their need.

SPECIAL-USE ACTIVITY CENTERS

The special users identified in this study fall into the two broad categories of agriculture and surface mining. A list of specific commodities was modified as industry characteristics were determined; the selected commodities are as follows:

Agriculture	*Surface Mining*
Timber	Sand and gravel
Grain	Crushed stone
Beef cattle	
Cotton	
Produce	

A flow chart of the study procedure is shown in Figure 1. Two scenarios are presented, one for current maintenance activities and the other for planning and design. In either scenario, site-specific trip generation rates must be determined

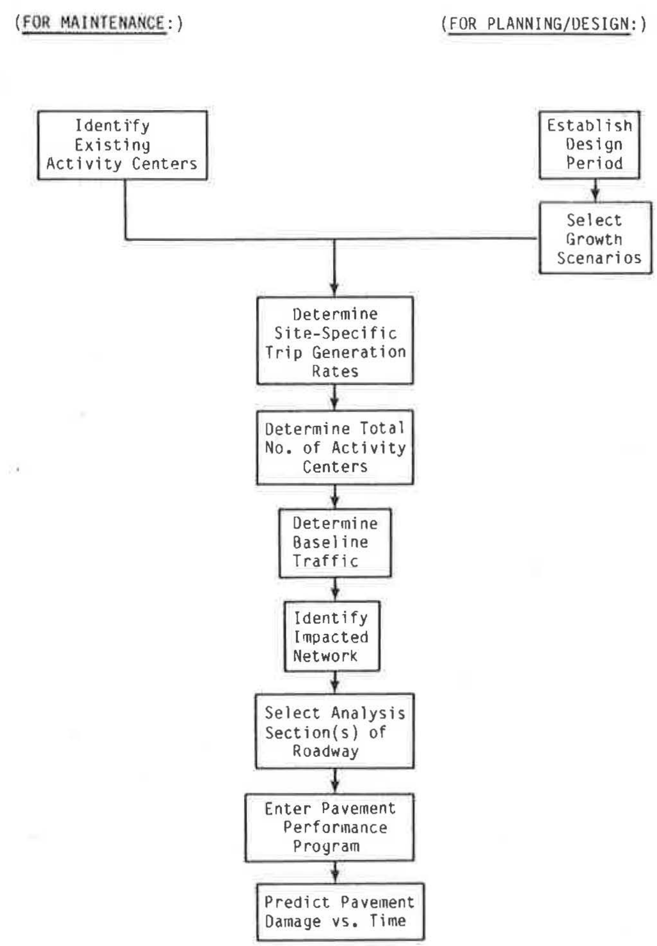

FIGURE 1 Study flow chart.

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for each activity center listed above, followed by a determination of the total trips of all activity centers nearby. The baseline traffic must be determined or estimated for the design year in order to establish incremental damage due to special-use activity centers.

The assignment of traffic can be accomplished with knowledge of specific industry characteristics. The affected network can then be approximated, and traffic can be assigned to study sections from appropriate activity centers. The computer program can then be used to predict pavement damage over time.

Methods of Collecting Information

First, several public agencies were contacted to determine what information already existed. In most cases, site visits to one or more of the activity centers of each commodity were conducted, which included interviews with key industry personnel. Telephone interviews were also used to supplement office interviews. Information gathered by interviews is shown in Tables 1 and 2. During the first year, manual classification counts were conducted at three timber activity centers, or mills.

The second year's data collection effort was focused entirely on individual activity centers and the site-specific impact of each center. The specific information sought was the radius of influence and the trip generation rates for activity centers of each special-use commodity. The radius of influence represented the maximum distance from an activity center at which vehicular traffic was generated. For trucks, the radius of influence was usually thought of as the haul distance from the loading site to the load destination or unloading site.

A random selection procedure was used to determine which activity centers should be studied throughout the state. This procedure involved the development of sample plans in such a way that the truck trip generation factors obtained would be representative of the entire state and be descriptive of variation in activity center size. In most cases, a two-stage process was used to select activity centers for manual and machine counts. The first step involved a random selection of counties in which the commodity was produced. The second stage involved a random selection of activity centers from the selected counties.

TABLE 1 SPECIAL-USE COMMODITY SUMMARY FROM OFFICE INTERVIEWS

Commodity (Activity Center)	Common Truck Silhouettes	Average Daily Truck Trips[a] Activity Center: Average	Large	Typical Radius of Influence (Miles)	Typical Weight Range (1,000 lbs)[b]: Tandem Axle	Gross Vehicle	Peak Season
Timber Mills							
Paper		350	550[c]	50	32-38	74-86	Mar.-Nov.
Plywood		150	350	50	32-38	74-86	Mar.-Nov.
Particleboard		150	300	50	32-38	74-86	Mar.-Nov.
Sawmill		150	250	50	32-38	74-86	Mar.-Nov.
Grain elevator		200	400[c]	20	32-40	76-90	May-July
Beef Cattle Feedlot		60	90	600	32-35	76-82	Year Round
Produce Distributor		200	500	20	32-36	72-80	Mar.-Apr.
Cotton Gin		40	110	20	30-36	72-82	Sep.-Dec.
Sand and Gravel Pit		600	1,100[c]	60	32-36	70-80	Mar.-Nov.
Limestone Quarry		1,400	2,800[c]	120	32-36	70-80	Mar.-Nov.

[a] One-way trips (one origin, one destination).
[b] Based on experience, conversation, limited weight information, and other research projects.
[c] Truck trip generation depends on percent rail. Rail is assumed to have negligible influence at these activity centers.

TABLE 2 SPECIAL-USE TRIP GENERATION FROM INTERVIEWS (PEAK SEASON)

Location (Activity Center)	Number of Passenger Cars per Day	Percent of One-Way Truck Trips per Day			Maximum Daily Truck Trips[a]
		SU	3-S2	Other Trucks	
Timber Mills					
Pulpwood	1,800	21	75	4	550
Plywood mill	650	5	90	5	325
Particleboard	650	12	84	4	300
Large sawmill	--[b]	4	80	16	250
Average sawmill	240	7	80	13	150
Grain Elevator	8-10	88	12	0	400
Beef Cattle					
Large feedlot	110-140	11	89	--	90
Average feedlot	50-60	16	84	--	50
Produce					
Large distributor	400-500	40	40	20	500
Average distributor	120	23	59	18	220
Cotton Gin	--	65	13	22	110
Sand and Gravel					
Large pit	140	5	95	--	1,000
Average pit		5	95	--	550
Limestone					
Large quarry	800	5	95	--	2,000
Average quarry	300	5	95	1,000	1,000

[a] One-way trips (one origin, one destination).
[b] Data are unavailable.

The number of activity centers selected throughout the state were as follows:

Commodity	*Number of Sites*
Timber	13 mills
Grain	12 elevators
Beef cattle	10 feedlots
Cotton	12 gins
Produce	6 distributors
Sand and gravel	15 pits
Limestone	15 quarries

Thus, from a total of several hundred activity centers statewide, 83 were selected for observation. A manual count procedure was used almost exclusively because of the difficulty in finding machine count stations that would clearly represent only traffic generated by the activity center.

The standard manual count form is depicted in Figure 2. A 1-day vehicle classification count was made for each site selected using 15-min intervals for all traffic entering and leaving the facility. Vehicles were classified as follows: SU-1 (single-unit, two-axle truck), SU-2 (single-unit, three-axle truck), 2-S1 (two-axle tractor, one-axle semi-trailer), 2-S2 (two-axle tractor, two-axle semi-trailer), 2-S1-2 (two-axle tractor, one-axle semi-trailer, two-axle full trailer), and so forth. The period of on-site observation ranged from 8 to 18 hrs. After the first year, data were collected in 3-day counts at each site to improve their reliability.

Pertinent Agriculture Industry Characteristics

Timber

Three types of mills—plywood, particleboard, and sawmills—were selected for evaluation. Logs were hauled from a cutting site to various mills at an average distance of 60 mi, and sometimes as much as 100 mi.

For practical purposes, trip generation at the cutting site was evaluated on a per-acre basis. Too many variables usually exist to accurately evaluate trips on a time basis. However, if inclement weather and machinery breakdowns are ignored, the following are the approximate monthly averages to be expected for a small, average, and large contractor in Texas:

Contractor Size	*No. of Acres*	*No. of 3-S2 Loads*[a] *Month*	*Day*[b]
Small			
Clear	20	45	3
Selective	45-50		
Average			
Clear	50	100	5
Selective	100		
Large			
Clear	150	300	15
Selective	300		

[a] Using 2.5 truck loads per acre, clear cut, and 1 truck load per acre, selective cut.
[b] Using a 5-day work week.

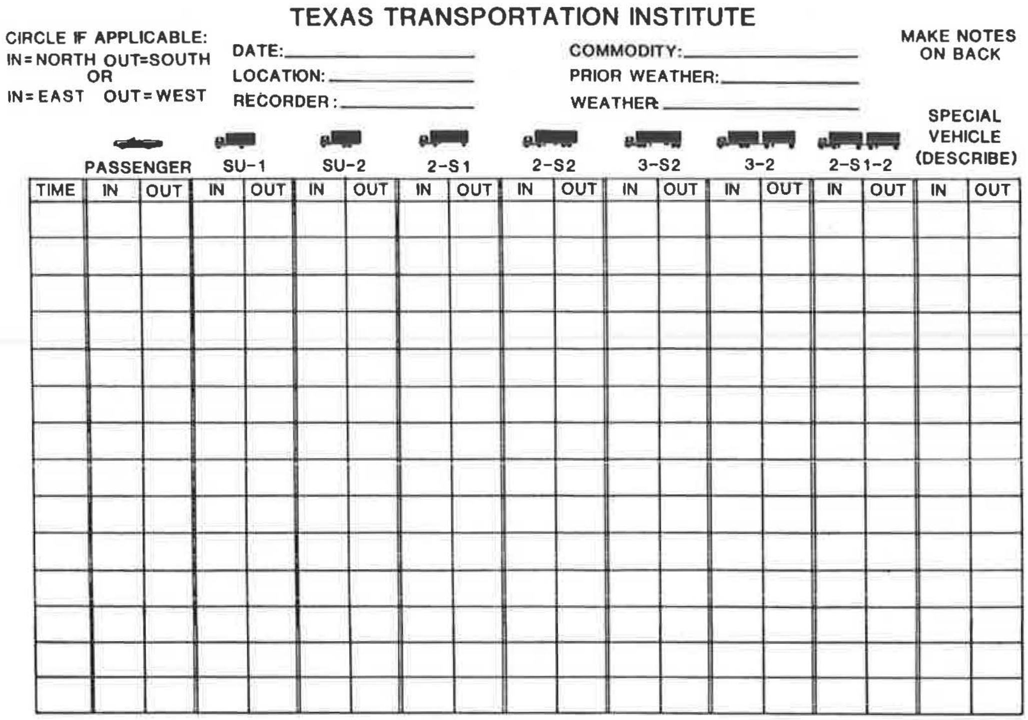


FIGURE 2 Standard manual count form.

Trip generation rates for large plywood, pulpwood, and particleboard mills were observed to be in the range of 200 to 400 one-way trips per day. Vehicle types surveyed were to be 80 to 90 percent combination vehicles (predominantly 3-S2). For a large sawmill, trip rates were observed to be between 150 and 300 per day, and 80 percent were made with combination vehicles, as shown in Table 3.

Timber truck movement is affected by the four factors of weather, the economy, railroads, and the timber's growing cycle. Significant rainfall slows and even completely stops timber cutting activity until the ground sufficiently dries. Timber truck activities are more intense in the months preceding the rainy season because the mills are stockpiling raw materials to maintain a constant level of production during the rainy months.

The economic situation is another important influence on the timber truck movement. When the construction industry is depressed, the demand for finished wood products is low, and the timber industry will therefore slow its harvesting efforts.

The use of railroads by the majority of timber mills, except paper mills, is insignificant. Paper mills receive some of their raw wood material by rail in the form of chips from other mills. They also transport some of their bulky paper items by rail, such as the paper used by newspapers and magazines.

Another characteristic of the timber industry involves the cycle of tree growth. Once an area has been clear cut, or all trees have been removed, it takes 15 to 35 yrs before the stand of trees is ready for another harvest. If trees are selectively cut, or only the largest trees in the area are removed, cutting may take place every 5 yrs.

Grain

The activity center of the grain elevator was used for short-term storage for those operations that were studied. The stored grain was shipped by truck to feedmills, other elevators, feedlots, and ports. The distance from the field to the elevator and from the elevator to the feedlot or feedmill was an average of 20 mi, whereas the distance from the elevator to a port was 200 to 300 mi. If the destinations were longer distances away, the grain was typically shipped by rail. Interviews of three elevator operators in east Texas yielded the following information:

Elevator	*Capacity (1,000 bushels)*	*Peak Season S-U Truck Loads (Per Day)*
A	359	80
B	415	70
C	2,000	100

Elevator A received its grain from area farms that were within 20 mi and sent 85 percent of this grain to a nearby feedmill. This feedmill needed one 3-S2 load of grain every 1 to 3 days. Elevator A shipped grain by rail little or not at all.

Elevator B shipped 50 percent of its grain by rail, mostly to feedmills. Most of the wheat and milo went to Gulf ports. Trucks that brought grain to Elevator B were predominantly SU-2s, but some SU-1s carried 25,000 to 36,000 lbs of grain. The haul distance was almost 20 mi. The peak intake was 2 million lbs per day, or approximately 70 truckloads.

Elevator C received 100 SU-2s during a peak day; each carried 12,000 to 30,000 lbs of grain. The grain came from area farms that were located within 20 mi of the elevator. The feedmill located next to the elevator produced 300 tons of meal per day. About 45 percent of the meal was shipped by rail. Other information gathered from interviews is given in Tables 1 and 2.

On-site counts for a 1-day period at 13 elevators yielded the following information (see Table 3). The total of daily truck

TABLE 3 MANUAL CLASSIFICATION TRAFFIC COUNTS

Activity Center	Size	Average Percentage of Combination Trucks	Average percentage of SU	Total Truck Trips[b]
Timber Mills				
Pulpwood mill	Large	83	17	291-435
Plywood mill	Average	80	20	64
	Large	92	8	196-281
Particleboard mill	Large	83	17	305-362
Sawmill	Small	54	46	65
	Average	77	23	82
	Large	79	21	161-264
Grain Elevator	Average	24	76	133-313
	Large	58	42	349-570
Produce Distributor	Small	24	76	23-34
	Average	69	31	125
	Large	44	56	340-379
Sand and Gravel Pit	Small	25	75	58-128
	Average	92	8	97-137
	Large	85	15	240-775
Limestone Quarry	Small	64	36	42-63
	Average	12	88	122-194
	Large	60	40	147-474

[a] Based on *preliminary survey data; subject to change.*
[b] One-way trips (one origin, one destination, and entering and exiting).

trips for average-sized operations was in the range of 100 to 300 one-way trips; approximately 80 percent of the trips were made by single-unit trucks, and the remainder was made by combinations. The number of daily truck trips generated for large elevators was 350 to 550, of which 60 percent were made by combinations and 40 percent by single-unit trucks.

Grain movement by truck is heaviest during the harvest season, which is May to July in Texas. Movement of grain can also be significant during other times of the year, depending on the demand at ports, feedlots, or feedmills. The grain is generally taken from the smaller storage elevators by truck and from the larger elevators by rail. As much as 45 to 100 percent of the grain movement from large elevators may be by rail, especially for distances greater than 300 mi. A smaller percentage of grain, typically 2 to 30 percent, is moved by rail, such as from one elevator to another or from an elevator to a feedlot.

A single-unit, three-axle truck is typically used to move the harvested grain from the field to the first elevator. A 3-S2 with a bottom-dump grain trailer is most commonly used to transport from the first elevator to feedlots, feedmills, or other grain elevators.

Beef Cattle

The feedlot was selected as an activity center. Trip generation rates were directly proportionate to size, given other similar factors. Information gathered from interviews indicated that a large feedlot, which had a capacity of 60,000 head of cattle, needed 44 3-S2 loads of feed, and shipped nine 3-S2 loads of fed cattle on an average day. Of the total of 55 employees of this feedlot, 40 were on an 8-hr shift, and 15 were employed on a 24-hr (three-shift) basis. A total of 110 to 140 daily passenger car (PC) trip-ends resulted.

An average-sized feedlot with a capacity of 23,000 head was also visited. Trucks that entered this feedlot during each 140-day cycle consisted of 255 loads (3-S2) of feeder cattle, 270 loads (SU) of silage, and 1,050 loads (3-S2) of corn; 510 loads (3-S2) of fed cattle left the feedlot. A daily average of 16 loads entered the lot and five left with fed cattle.

Most of the fed cattle were transported to a beef processing plant or to the cattle auction, both of which were located an average of 30 to 40 mi from the feedlots. Feed cattle were brought in from as far away as 1,500 mi. Information gathered from interviews is summarized in Tables 1 and 2. Since field data collected for beef cattle were incomplete, they were not included in Table 3.

Cotton

The next activity center chosen was the cotton gin. Cotton is typically hauled from field to gin in cotton trailers or module trucks over an average distance of 15 to 20 mi. Module trucks are three-axle, single-unit trucks; cotton trailers typically have two axles.

An average gin that operates 24 hours a day can handle 150 bales or 15 modules of seed cotton a day. Larger gins can receive and process 500 bales or 50 modules per 24-hour shift. Each module represents one SU-2 coming into the gin. Trucks leaving the gin haul from 50 to 90 bales, typically closer to 90. For an average gin, this means almost two 3-S2 loads leave per day and for a large gin, about six loads. This cotton is hauled to a compress that may be from 10 to 100 mi away.

The harvesting season in the panhandle area of Texas is typically October 15 to January 15, depending on the weather. Southern parts of the state typically begin to harvest a few weeks earlier. Cotton shipped from the panhandle area generally goes in three directions. About two-thirds of the cotton is sent to the West Coast and to Texas ports for export. Cotton shipped to the West Coast travels by rail, whereas that shipped to Texas ports and mills in the southeastern United States goes by truck.

Because field data are incomplete for cotton, the results are not included in Table 3. However, the data can be summarized as follows. The number of observed trip-ends at small, average, and large gins was 50, 40 to 100, and 120 to 150, respectively. The variation in observed values is probably due to harsh weather conditions that existed prior to the survey, variations in length of work day from one gin to another, and the limited number of sites (five) surveyed. The compress for three of the gins was only 30 to 40 mi away, whereas it was over 300 mi away from the other gins. In one case, cotton seeds were hauled 200 mi. The use of module trucks seemed to be greater for average- to large-sized gins (average 55 percent) than for small ones.

Produce

The produce distributor was chosen as the activity center to be studied. The distributor is the first point of processing after produce leaves the field. Because a freeze in 1983 completely destroyed the citrus crop in Texas, the movement of citrus fruit was not included in this analysis.

A phone interview with a large distributor resulted in the following information. During the peak shipping season, an average of 200 vehicle-loads (SU-2 and field tractor pulling one or two field trailers) per day were received. An average of 75 to 100, and a maximum of 200, 3-S2 truckloads left per day. A total number of 200 to 250 employees worked one shift, 8 a.m. to 6 p.m.

A slightly larger than average distributor was visited. A total of 46 loaded field vehicles entered this facility on a typical day. These arrivals were fairly constant from 11 a.m. to 4 p.m., and very few came in after that time. Fifteen vehicles were unloaded during the first hour of operation, from 6 a.m. to 7 a.m. The SU-2 (3-axle "bobtail") was commonly used to haul produce from the field to the distributor. A limited sample of weights showed that approximately 7,000 lbs were on the steer axle and 25,000 lbs on the drive tandem, with a payload of about 20,000 lbs. The bulk of 3S-2 loaded refrigerated vehicles left the distributor from 2 p.m. to the early morning hours. The peak departures occurred around midnight.

Single-unit trucks or farm trailers were loaded by hand in the fields where the produce was grown. These vehicles then traveled 15 to 50 mi on low-volume, farm-to-market roads to a local distributor. The distributor packaged or crated the produce and loaded it into a refrigerated van (3-S2), which was owned by a private owner or contractor. This van then carried the produce hundreds of miles to a supermarket warehouse for immediate distribution or possibly to a processing plant for canning.

The various individual fruits and vegetables were harvested during different times of the year; produce trucks therefore hauled throughout most of the year. A small peak in traffic occurred during March and April and a small decline occurred in the fall around August and September. Weather is a major influence on the movement of produce by truck. If the crop yield is high because of good weather, then the demand for trucks is greater.

The observed daily trip generation rates for six activity centers are summarized in Table 3. Daily truck trip-ends for a small distributor were less than 50; for an average distributor, over 100; and for a large distributor, about 350.

Pertinent Surface Mining Industry Characteristics

Sand and Gravel

Actual site visits and office interviews of industry representatives yielded the following information. The gravel pit was chosen as the activity center to be analyzed. Sand and gravel were hauled on low-volume public roads from the mining area to the construction site or to asphalt batch plants or concrete plants.

A large sand and gravel operation had a capacity of 1,250 tons per hour, which meant that roughly 25 trucks per hour, or 370 truckloads per day, left the pit. The maximum number of loads possible per day was 550. The average distance traveled per day per truck was 300 mi over a radius of about 60 mi. On an annual basis, this operation moved about 2.5 million tons of gravel, none by rail. An average plant handles 500,000 to 750,000 tons per year, 60 percent of which is sold immediately and the remainder stockpiled for later use. Over the long term, all gravel is sold but a surplus of sand remains.

The actual field observations of several sand and gravel operations are summarized in Table 3. The data collected for this commodity are incomplete, but the number of truck trip-ends observed were: 60 to 120 for small pits, 100 to 140 for average pits, and 240 to 780 for large pits. Roughly 90 percent of the vehicles that were used at average and large pits were combination vehicles, predominantly 3-S2s.

Limestone

Actual sites were visited and industry representatives were interviewed to gather the pertinent information. The quarry was chosen as the activity center for this study. As the rock is mined, it is run through a crusher, then segregated by size. The sized material is then either stockpiled or hauled away immediately by truck or rail. One large firm hauled 22 percent of its aggregate by rail in 1983. This amount varied somewhat from one quarry to the other, but was usually 20 to 30 percent.

A large quarry loads 900 to 1,000 truckloads (mostly 3-S2s) on an average day. The maximum is about 1,400 loads. Employee work trips are another 800 trip-ends per average day. The production of this quarry decreases by about 20 percent in the months of January through March.

A slightly larger than average limestone quarry usually produces 450 truckloads per day, and a maximum of 700 loads per day. Its radius of influence extends 125 mi, and about 10 percent is transported by rail. The capacity of this operation is 2,000 to 2,200 tons per hour, or about 100 truckloads per hour. Employees add another 300 trip-ends per day.

The observed trip generation factors are listed in Table 3, although surveys were incomplete for this commodity. The observed values were 40 to 60 for small quarries, 120 to 200 for average quarries, and 150 to 470 for large quarries.

USE OF PAVEMENT PERFORMANCE EQUATIONS FOR SPECIAL-USE ACTIVITIES

A technique that was previously developed for pavements that were affected by oil field activities was adapted to predict the performance of thin-surface-treated pavements near the special-use activity centers described earlier (*2, 3*). The following is an overview of the development process and the pavement model used in Texas.

As the AASHO Road Test drew to a close, one of the strongest recommendations made by the test staff was that satellite studies should be performed in other parts of the country to objectively determine the real effects of subgrade and climate on pavement. Texas participated in these studies by establishing a flexible data base that contained detailed data on more than 400 sections of pavement (*4*).

Of these 400 sections, 132 are on thin-surface-treated pavements on farm-to-market (FM) roadways. These thin pavement sections were chosen to be analyzed in the study of oil field activities while the pavement damage model was being developed. These roads typically carry between 100 and 750 vehicles per day and were constructed with granular base courses that ranged in thickness from 4 to 10 in.

Data collection on these sections started in 1972, when the full construction, maintenance, and traffic history of each section was compiled. Riding quality (PSI), distress, and skid surveys have been made periodically on all pavement sections since 1973. In most cases, five or six separate observations have been made on each section since the survey began.

During the distress survey, the following eight types of distress were observed: alligator cracking, transverse cracking, longitudinal cracking, rutting, raveling, flushing (or bleeding), failures (potholes), and patching. Each of these types of distress was rated for its area and severity according to the distress identification manual prepared for the State of Texas (*5*).

In the early research of oil fields, a different form of damage function was assumed than that resulting from the AASHO Road Test. A sigmoidal (S-shaped) curve, shown in Figure 3, provided a better representation of actual pavement performance in Texas than the original AASHO Road Test damage function (*6-8*). The assumed form of the damage function for Texas flexible pavement is

$$g = \exp - (\rho / N)^{\beta} \quad (1)$$

where

g = normalized damage,
N = number of 80-kN equivalent SALs, and
ρ and β = constants for each pavement section.

Space does not permit a full description of the analysis undertaken to produce the pavement performance equations used in this study. However, the procedure and typical equations have been published elsewhere (*9*). The following is an overview of the procedure.

1. For each pavement section, an analysis was made of the observed distress and serviceability index histories to determine the values of ρ and β.
2. SAS stepwise regression (*10*) was then used to perform a regression analysis to explain the variations of ρ and β between sections of the same pavement type. The determined final

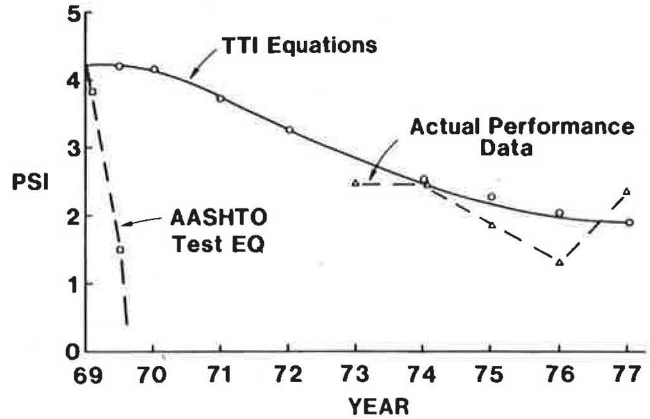


FIGURE 3 Regression equation versus actual performance.

regression equations are as follows: ρ is a function of climate, base thickness, and subgrade properties. An example of an equation for rutting area is as follows:

$$\rho = [-0.1035 + 0.005\,49(AVT) + 0.006\,70(D) - 0.0015(LL) + 0.001\,62(PI) + 0.000\,77(FTC)] \times 10^6 \quad R^2 = 0.38 \quad (2)$$

where

AVT = average district temperature (°F - 50°F),
D = thickness of flexible base course,
LL = liquid limit of subgrade soil,
PI = plasticity index of subgrade soil, and
FTC = average number of annual air freeze-thaw cycles.

Such equations have been generated for each of the eight distress types and PSI. The correlation coefficients (R^2) of these equations in general range from 0.30 to 0.60. No acceptable models were found for a few distress types, particularly raveling and flushing. In these instances, the mean values of ρ and/or β were used for predictive purposes.

Like other models for the prediction of pavement distress reported in the literature, the models used in this study generally have low R^2 values. The cause of these low R^2 values can be traced to several sources, including the subjectivity of ratings and the unavailability of some important variables. Two approaches were taken to justify the use of these models. First, their predictions of pavement performance were compared with actual performance (Figure 3). The second approach involved asking experienced field engineers to comment on the predictions.

Unlike the AASHO Road Test, in which damage was assessed in terms of reduction in PSI, this study defined damage as a combination of distress and loss of serviceability index, called "pavement score." This composite index used by Texas was calculated by using the following equation and then multiplying this "utility score" by 100 (*11*).

$$\text{Pavement utility score} = U_{RIDE}^{a_1} \times U_{DIST}^{a_2} \quad (3)$$

where

U_{RIDE} = the riding quality utility score of range 0-1;
U_{DIST} = the visual distress utility score of range 0-1; and
a_1 and a_2 = weighting factors on each utility score.

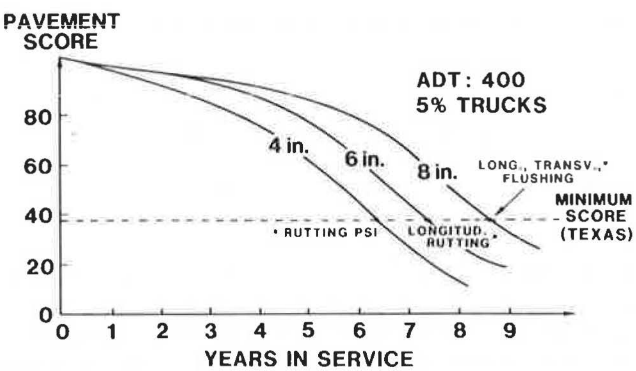
The visual distress utility score is further defined as

$$U_{DIST} = (U_{rut})^{b_1} (U_{ravel})^{b_2} (U_{flush})^{b_3} (U_{failures})^{b_4} (U_{allig.})^{b_5} (U_{long.})^{b_6} (U_{trans.})^{b_7} \quad (4)$$

where each U_i value is determined from the visual inspection data and has a 0-1 range and the b_i are weighting factors.

When the Texas definition of pavement score is used, if any single utility value becomes low, the pavement utility score will be low. For instance, if the ride value of the highway falls to a critical level, then the pavement score drops to a failure level. Alternatively, a pavement score may reach failure due to a combination of distress types and still maintain a high PSI. In Texas, new pavements have a pavement score of 100; failure level for surface-treated roads is defined at a pavement score of 35.

Verification of results obtained from this technique was accomplished by showing predictions, such as those in Figure 4, to a panel of experienced engineers. They generally concluded that these predictions were reasonable for these types of pavements under the specific loading and environmental conditions.



*Predicted cause of failure

FIGURE 4 Pavement score versus time.

A computer program was written to incorporate the Texas pavement distress equations and pavement score concepts. The program uses traffic classification data to calculate the expected 80-kN (18-kip) equivalent single-axle loading for a preselected analysis period. The distress equations predict pavement condition, hence pavement score, for each subsequent year. When the pavement score reaches a predetermined failure level (pavement score = 35), the number of months to failure is calculated. For a particular failure level, it is possible to determine which types of distress have caused the reduction in pavement life and consequently which rehabilitation strategy should be considered.

CASE STUDY

A case study was conducted to show how the pavement damage program and the acquired knowledge of special-use truck traffic can be used to assess low-volume roadway pavements. The impact of a large timber-cutting site in the Sam Houston National Forest in east Texas was chosen to be evaluated. The cutting site is accessed by two farm-to-market roads, FM 2296 and FM 1375, which are used equally by timber trucks hauling from the site to the mill. These roads are 20- to 22-ft, surface-treated roads with a 9-in base and seal coat. FM 1375 was chosen as the road to be evaluated. Before the timber contractor began cutting, the ADT of the roadway was 1,000 vehicles, 11 percent of which were trucks, and a 5 percent predicted growth rate per year.

Timber was harvested for 7 months; approximately 400 acres of timber were clear cut per month, which meant that 35 to 40 truckloads left the cutting site each work day. The timber traffic began 17 months after major resurfacing work was done on FM 1375.

This information was used as an input into the pavement damage program to predict the decrease in serviceability because of this specific timber traffic (*2*). The results of the program indicated that, under baseline conditions, the road should be resurfaced after approximately 37 months. This appears reasonable because the road has been resurfaced approximately every 3 years under baseline traffic. Other results of the program indicate that the additional traffic means that the road should be resurfaced approximately 6 months earlier than would be necessary under the baseline growth in traffic. This is shown in Figure 5 by the difference in time (months) before the predicted pavement score is reduced to 35.

In reality, roads of similar design in the area are failing faster than the program predicted. It is believed that this discrepancy is due to the conservative weight distribution used in the program to calculate equivalent axle loads. The weight tables used were gross averages compiled by the State of Texas for different regions of the state and account for all types of trucks that use a particular roadway. The traffic on FM 1375, which now includes baseline traffic and national forest timber traffic, is believed to be significantly heavier than that represented by the weight tables. According to representatives of the industry, the average gross weight of these timber trucks is approximately 100,000 lbs. A better estimate of pavement performance is anticipated after the weights of these vehicles are more accurately represented.

Nevertheless, the case study demonstrates a method by which such special-use traffic generators can be analyzed. The results can be used to schedule maintenance and select an appropriate rehabilitation strategy for various classes of roadway. Trip generation information can also be used in the traditional application of calculating traffic volume estimates and projections for a specific generator. Although the sizes and other characteristics of specific, special-use activity centers may vary somewhat from those examined in this study, the approach to evaluating the traffic impact will remain the same. More research in these same industries is being performed, and a more complete data base will be available to maintenance and planning personnel.

SUMMARY AND CONCLUSIONS

The study of special-use truck traffic involved the traffic associated with the processing and transporting of timber, beef cattle, cotton, grain, produce, sand and gravel, and limestone. This traffic may be unique in terms of vehicle distribution, axle configurations, axle loads, and seasonal fluctuations. This type of traffic is often found on low-volume, farm-to-market roads,

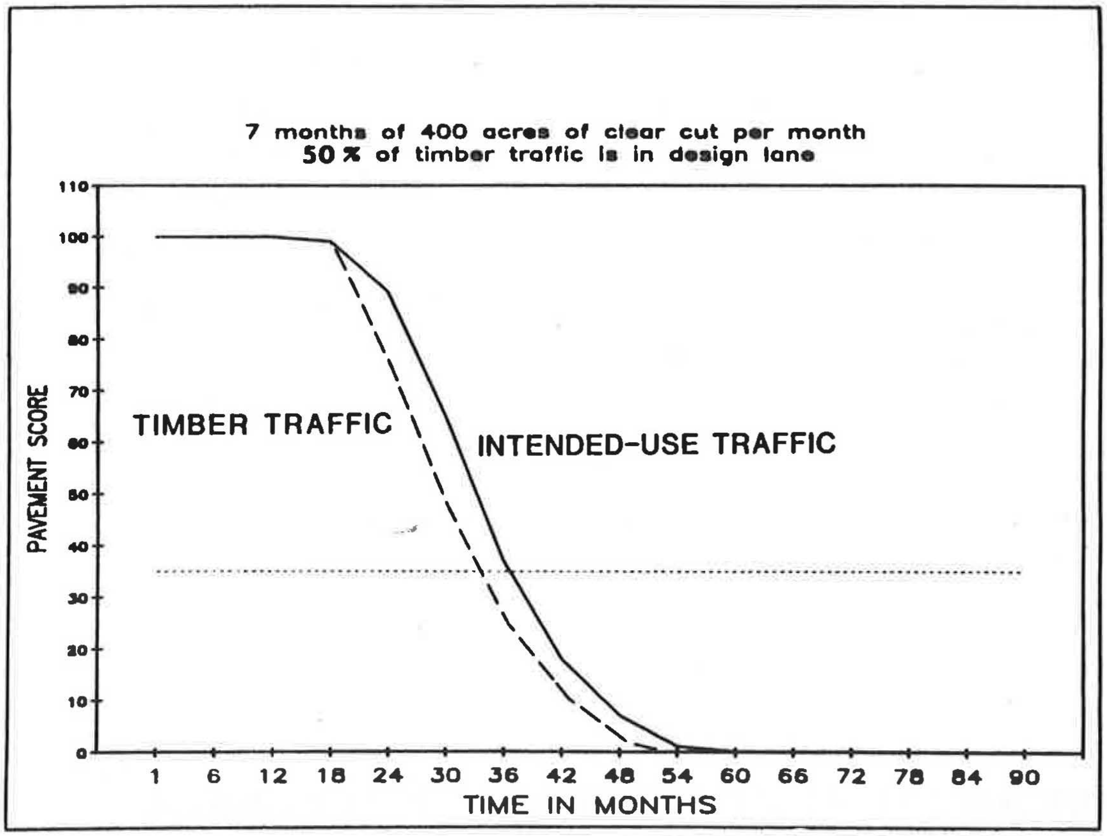


FIGURE 5 Predicted pavement score with timber harvest site development.

and causes the percentage of trucks to be significantly higher than is normally expected at the design stage.

Among the many vehicle types found in these special-use industries, the most common is the 3-S2, which uses a variety of trailers. The rear-dump trailer has been the most common in the sand and gravel and limestone industries, although double trailers that dump from the bottom are becoming more commonplace. Grain haulers use a specialized grain trailer that dumps from the bottom. Beef cattle are usually transported on a 40-ft-long, two-level enclosed trailer called a "possum-belly," while timber haulers use two specialized trailers to haul either tree-length logs or pulpwood (8-ft lengths) from the forests to the mills. Refrigerated vans (3-S2s) are used to haul beef and produce after processing. Flat-bed trailers haul finished timber products from mills and cotton from gins. Single-unit trucks are used extensively to haul produce from field to distributor and to haul grain from field to elevator.

The impact of the various special-use activity centers must be evaluated in terms of truck trips generated per unit time or area, radius of influence, and seasonal fluctuation. Information gathered by interviews is summarized by commodity in Tables 1 and 2.

The timber case study demonstrated how information on special-use truck traffic can be used. The cutting site generated 35 to 40 truckloads (3-S2s) of logs per day, which were hauled on two surface-treated roads to a mill 5 mi away. The pavement damage program indicated that the additional traffic demand would require that the road be resurfaced approximately 6 months earlier than would be necessary under baseline traffic only.

In conclusion, the results of this preliminary investigation indicate that traffic generated by these industries, in addition to baseline traffic, exceeds the intended design purpose of many roadways. In some cases, this was because certain trucks carried more weight than they should have, whereas in other situations, it was because legally loaded trucks made more trips than were anticipated.

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Consideration of Seasonal Pavement Damage for Timber Haul Roads

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Timber haul roads are subjected to severe use conditions that make them highly susceptible to seasonal impacts. They are located in areas of extreme terrain and environmental conditions, are constructed with minimal investment in the pavement section, and support extensive traffic from heavily loaded timber trucks. This multiyear study was undertaken to evaluate relative, traffic-induced damage to roads used at different times of the year and to provide rationally based road management alternatives. The field evaluation of the pavement section was performed by using periodic surface deflection measurements that were obtained with a Benkelman Beam, and included pavement temperature measurements at the test locations. The laboratory material characterization included the determination of resilient modulus relationships for cored asphalt concrete samples and for aggregate and subgrade materials. The assessment of laboratory and field data was performed by using computerized mechanistic analysis techniques, in which the pavement structure was considered a linear elastic multilayered system and the layered materials were characterized by their resilient modulus and dynamic strain ratios. The evaluation criterion was the fatigue life of the asphalt concrete as correlated with limiting elastic strains. Relative damage ratios were established for different seasons and were found to be significant and predictable for the roads under study.

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INTRODUCTION

Wide-ranging seasonal changes in climate subject low-volume roads worldwide to severe use conditions. An understanding of the roadway's response to such seasonal changes and the long-term effect on the pavement structure is critical to the development of rationally based management programs. In consideration of these points, an analysis of seasonal use impacts of paved timber haul roads was undertaken by evaluating several roads in the Sierra Nevada Mountains of California. The assessment of seasonal effects was focused on the spring thaw period, when subgrade soils are saturated and temperature shifts can be extreme. A comparison was then made with periods of strength recovery during the summer and fall when the subgrade dries.

Surface deflections and pavement temperatures were measured at representative locations on four different roadways over a 4-year period in order to characterize seasonal responses to climatic changes (*1, 2*). Asphalt concrete, aggregate base, and subgrade samples were obtained from two roads that were selected for detailed study and were tested in the laboratory to determine their relevant engineering properties.