Analysis of Pavement Damage Attributable to Overweight Trucks in New Jersey

RICARDO T. BARROS

ABSTRACT

A study was undertaken to quantify the magnitude of the pavement damage done by overweight trucks in New Jersey. This was accomplished using the AASHTO 18-kip equivalent axle load parameter, established engineering-economic procedures, and data obtained from the New Jersey State Police. Questions specifically addressed include (a) How much pavement damage is attributable to overweight trucks? (b) What are the costs associated with this damage? (c) Are these costs adequately covered by the revenues collected from the overweight violators? (d) Is mandatory off-loading (requiring violators to immediately lighten their loads at the ticketed location) justifiable? It was found that detected overweight trucks cause a relatively small shortening of pavement life and, had they been successfully off-loaded, a negligible savings would have resulted. However, there is serious concern that the number of overweight trucks actually detected represents only a small fraction of the total number of overweight violators. Attempts to estimate the total overweight truck population suggest that the total pavement damage attributable to all overweight trucks may approach $20 million per year. It was therefore concluded that a substantial increase in the revenue generated by overweight trucks may be appropriate.

The consequences of operating overweight trucks are a timely concern, particularly in light of the Surface Transportation Assistance Act (STAA) of 1982 that standardized truck size and weight restrictions across the nation. This analysis, requested by the Office of the Attorney General of New Jersey, specifically addresses the engineering and economic implications of excessive pavement loading in a state where maximum weight limits already comply with the federally mandated standards (1). Knowledge of these implications should provide guidance in making policy decisions pertinent to the mode and level of truck weight enforcement. This required that pavement damage be defined in terms of an established parameter and that the extent of this damage be quantified in a rational manner.

It is common knowledge to highway engineers that pavement damage increases dramatically with increasing vehicle weights. A legal, fully loaded tractor trailer combination may cause approximately 10,000 times the pavement damage caused by the heaviest of passenger cars. Intuitively, it might appear that illegally loaded trucks would cause substantially more damage than their legally loaded counterparts. However, this inference is only partly correct.

Analysis of the comparative pavement damage resulting from the myriad possible vehicle loadings is conveniently accomplished with the AASHTO 18-kip (18,000-lb) equivalent axle load (EAL) parameter (2, pp. 162-167). This parameter was developed to provide a common basis against which to assess the effect of repetitive loads on pavement serviceability. It permits information on vehicle configuration and weight on each axle grouping to be transformed into a single fundamental parameter, expressed as multiples of the pavement damage done by the standard 18-kip single axle load used in pavement design. A 28-kip load on a tandem axle on a 9-in. rigid pavement, for example, will ordinarily cause only 85 percent of the damage that would be done were an 18-kip load on a single axle applied to the same pavement. Thus the 28-kip tandem axle load may be described as doing 0.85 EAL damage. Given a specified pavement, either flexible or rigid, a measure of the pavement's strength, and a definition of the condition beyond which the pavement's serviceability is considered unsatisfactory, the EAL impact of any vehicle is simply summed from the EALs of each contributory axle group.

EAL analyses are straightforward and make it possible to quantify the relative damage sustained by a pavement for any specified combination of axle type, axle load, and pavement structure. Then, to predict the wear and tear actually sustained by a pavement, it is necessary to estimate the frequency with which each type of loading will be applied. Thus the distribution of vehicle types, as well as the frequency distribution for each vehicle type, must be considered in estimating the serviceability extracted from a pavement by the traffic loading.

If the applied traffic loading is known, and if a pavement's strength can be characterized, the EAL parameter can be used to estimate both the pavement damage and the economic loss resulting from overweight trucks. The following questions have been addressed in this analysis:

1. How much pavement damage is attributable to detected overweight trucks?
2. How much pavement damage is attributable to all overweight trucks?
3. What costs are associated with this damage?
4. Does the existing overweight fine structure adequately cover the losses suffered by the highway agency?
5. Is mandatory off-loading of excess weight (requiring overweight violators to immediately lighten their loads at the ticketed location) justifiable?
6. Finally, from a broader perspective, what toll would be exacted from the pavement system if

the enforcement program caused the same load to be carried by a larger number of legally loaded trucks?

SOME BASIC ASSUMPTIONS

Despite the narrow focus of the five questions posed, the scope of the analytical techniques used in their resolution was exceptionally broad. Statistical, engineering, and economic methods were used to transform raw overweight violation data into a meaningful indicator of marginal pavement damage in order to determine the efficacy of selected enforcement policies. This required that several assumptions be made. The most general of these were that

1. The AASHTO EAL parameter provides a rational means by which to apportion the consumption of pavement serviceability among the various vehicles using a roadway, and an increased rate of EAL application will proportionately reduce the life of a pavement.
2. Summonses issued by the state police for truck weight violations represent genuine excess loadings and culminate in the payment of legally prescribed fines. Also, the nature and total number of all overweight violators are approximately estimable from the summonses issued.
3. The characteristics of the overweight truck fleet observed in one year can be assumed to represent the characteristics of overweight truck fleets in future years.
4. The net cost associated with rescheduling planned overlays to earlier dates, plus the cost of truck weight enforcement, plus the (unquantified) cost in bridge damage, all expressed as their present worth, constitute the total economic loss exclusively attributable to overweight trucks.

OVERWEIGHT TRUCK DATA

The New Jersey State Police is the primary agency responsible for truck weight enforcement in New Jersey. Both portable and permanent weigh scales are used in this effort. Trucks found to exceed statutory weight limits are issued summonses for a violation of the Motor Vehicle Code and more than 9,000 summonses for overweight violations were issued in FY 1981. A sample of 2,265 violators taken from this population was used in this analysis, and the results were scaled upward to include the effect of unsampled citations. The sampled information included the distribution of actual and allowable weights as well as the class of road on which the violators were traveling. (Roads were classified as Interstate, state, or local and county.)

There is some doubt that detected overweight violators provide a representative sample of the entire overweight truck population because several potential biasing factors are readily apparent. First, permanent weigh stations have generally established hours of operation and known periods of inactivity. For example, they may not operate on weekends. It is reasonable to assume that an experienced driver who knew he was operating an overweight vehicle would choose an alternate route during those hours during which permanent weigh stations were open. For precisely this reason, portable weigh scales are strategically deployed. Certainly, the first trucks stopped at the permanent weigh stations may provide an unbiased glimpse of the overall overweight truck population, but the ubiquitous communication network made possible by citizens' band radios quickly alerts oncoming trucks to the weighing activity. It is suspected that some trucks that do not choose an alternate route may simply pull to the side to outwait the scale's operation (3,p.69). Also, roving enforcers selectively pull over individual trucks that display signs of a weight violation, such as slow speeds on inclines or an overly large tire imprint. Because of the overweight indications themselves, these enforcers are much more likely to detect a large weight violation than a small one. Finally, the correspondence between the number of detected violators and the total number of violators is difficult to establish. Summonses issued depend on several factors, including the size of the enforcement task force and the enforcement effort, so that any attempt to estimate the total number of violators as a multiple of the number of summonses issued is approximate at best.

Despite these numerous obstacles, an attempt is made to estimate the impact of all overweight trucks (both detected and undetected) in a later section. To take in this broader perspective, an admittedly lower degree of precision must be tolerated. Nevertheless, it is believed that this analytical methodology provides the best information currently available.

TRUCK WEIGHT VIOLATIONS AND FINES

In New Jersey there are several types of possible excess weight violations. A maximum load of 22.4 kips is allowed on any single axle, a maximum load of 34.0 kips is allowed on any tandem axle, and the maximum allowable gross weight is 80.0 kips for any truck. In addition, trucks may register at a lesser gross vehicle weight and pay a correspondingly reduced registration fee. This provision makes registered weight violations possible. That is, a truck registered to carry 10,000 lb may be cited when it transports an 11,000-lb load, even though this load is well below the 22,400 lb allowed on any one axle. Other violation types include triaxle violations and other vehicle-specific limits, such as a limit specifically applicable to a solid waste truck with a triaxle configuration. It should be noted that whenever a truck is found to be in violation of several limits simultaneously, the statute (before September 1983) permitted a court to assess only the single penalty associated with the largest fine. Thus only a tandem axle violation would be charged if a truck exceeded the tandem axle limit by a greater amount than it did the maximum gross weight limit.

A summary of one year's violation data is given in Table 1 and the frequency distributions for several of these violation types are shown in Figure 1. It can be seen that these distributions have a strong tendency to skew away from their respective limits and that only a small portion of the violations exceed their respective limits by more than 10,000 lb.

The overweight fine schedule used in New Jersey before September 1983 is given in Table 2. Applica-

TABLE 1 Frequency of Known Weight Violators by Cited Violation Type

Violation Type	Total Known Violations	Total Excess Weight (kips)	Average Excess Weight per Violation (lb)
Single axle	816	3,036.6	3,721
Tandem axle	4,752	22,858.1	4,810
Gross weight	1,392	9,493.9	6,820
Registered	1,500	7,473.9	4,982
Other	600	4,258.9	7,098
Total	9,060	47,120.5	

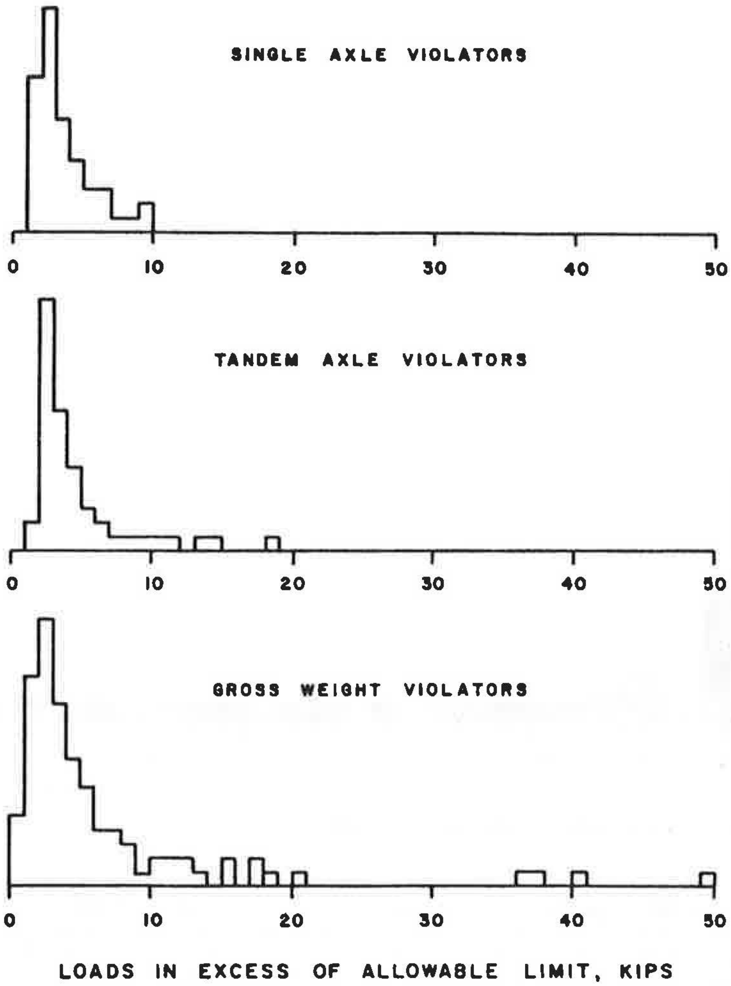

FIGURE 1 Relative frequencies of excessive weights for three violation types.

TABLE 2 New Jersey's Fine Schedule for Overweight Trucks Before September 1983

Excess Weight (lb)	Penalty ($)
0.0 to 2,500.0	50.00
2,500.1 to 10,000.0	0.02 per excess pound above legal limit
10,000.1 and more	0.03 per excess pound above legal limit

tion of this schedule to the truck fleet modeled in this analysis results in an annual revenue of $1.1 million, a figure consistent with actual data (source: Magistrates Fines Sections, New Jersey Department of Transportation).

The relative frequency distribution of assessed fines is shown in Figure 2. The distribution is discontinuous because of the abrupt increase in the penalty rate whenever excess weights exceed 10,000 lb. It is interesting to note that 91 percent of the violators would be charged less than $200 and that the other 9 percent, who are charged more, account for approximately 25 percent of the total revenue.

PAVEMENT DAMAGE MODEL

Pavements are designed and constructed with the knowledge that they will ultimately wear out. In practice, rehabilitation procedures are implemented before complete failure occurs and, consequently, a means by which to gauge the serviceability rendered must be established. Two of the possible approaches in modeling pavement serviceability would apply either mechanistic or empirical analyses. Mechanistic analyses are sophisticated, highly detailed investigations of the load distribution within a pavement structure and of the associated stresses and strains. They offer the advantage of isolating specific pavement failure modes, such as excessive rutting or cracking, but may be criticized for an overstated precision. Empirical analyses have an unabashedly straightforward derivation--materials, design elements, and construction techniques are correlated with service. Thus empirically based models provide a coarser level of information, but this information is more easily obtained and more easily digested. The following analysis will make use of the 18-kip equivalent axle load (EAL) parameter that represents an empirical-type model.

According to the AASHTO design procedure (4), pavements are designed to carry a specified number of loads during a predetermined period of time. Typically, for a rigid pavement, this may be 10 million EALs over a 20-year life. Assuming, for the sake of simplicity, a constant annual traffic flow, this corresponds to a design value of 500,000 EALs per year. If trucks operating over a pavement apply loads equivalent to 50,000 EALs annually, it can be stated that 10 percent of the pavement's service-

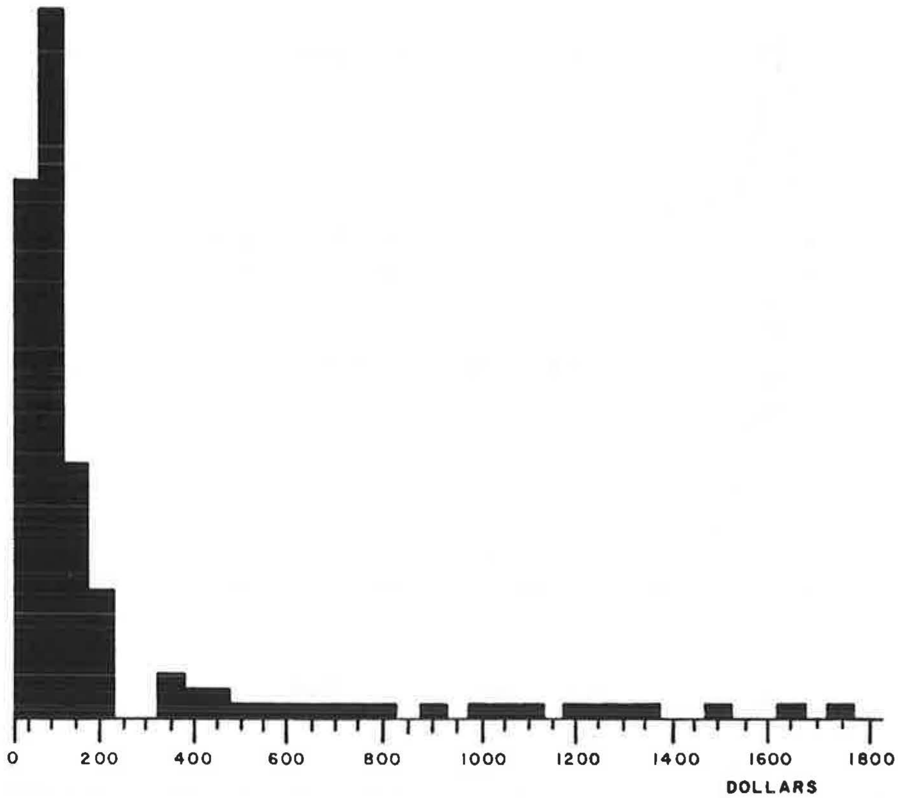

FIGURE 2 Relative frequency histogram of assessed fines.

ability is apportioned to this type of traffic. If the pavement damage attributable to trucks were to double, 20 percent of the design EALs would be exhausted by trucks, and it is assumed that the pavement would fail proportionately sooner.

The analytical model was based primarily on this relationship. Although highway engineers do allow for truck traffic in their pavement designs, usually planning on 10 to 30 percent trucks in the traffic mix, it is unlikely that they contemplate overweight trucks on a regular basis. Thus all overweight trucks are considered to be unplanned pavement loadings. These loadings reduce the predicted pavement life from its design value, resulting in an associated cost that can be reasonably quantified.

The development of a pavement utilization model required that several specific determinations be made, and these will be summarized briefly. The first of these was to develop a model truck fleet. This was necessary because actual violation data were not fully descriptive of the violating vehicle. In the case of single-axle and tandem-axle violations, raw violation data pertained exclusively to the violating axle group. In the cases of gross-weight and registered-weight violations, raw violation data pertained to the overall weight and not to axle-specific loadings. In all cases it was necessary to describe each violation in terms of an appropriate hypothetical truck for which all axle groups and axle loadings were known. Determination of the possible truck configurations was based on an auxiliary, detailed sample and resulted in a truck fleet partially shown in Figure 3. These truck configurations were used to estimate gross truck weights from single- and tandem-axle violation data, which include unreported axle groups, and to reduce gross- and registered-weight violations to axle-specific loadings.

The second preliminary determination involved the development of a typical New Jersey road over which the modeled trucks would travel. Approximately two-thirds of New Jersey's state roads are of flexible pavement, including composite pavement (rigid pavement overlaid with bituminous material), and about one-third is rigid pavement. It was assumed that all flexible pavements have a structural number of 5.0, reflecting a relatively strong section. New Jersey's rigid pavements are commonly 9.0 in. thick. Interstate pavements were reasoned to be at least as strong as state-owned pavements and, although local and county roads are generally less strong and predominantly bituminous, local and county pavements are also assigned a structural number of 5.0. (In the aggregate, assigning local and county roads a conservatively low structural number of 2.0 produced a negligible effect on the cumulative damage estimate.)

A typical mile of New Jersey pavement, therefore, was modeled in two sections: one-third rigid pavement, 9.0 in. thick, and two-thirds flexible pavement with a structural number of 5.0. On the basis of typical design considerations, 500,000 EALs are apportioned to each year of the pavement's design life. (This corresponds to roughly 10 million EALs over 20 years for rigid pavements and to 5 million EALs over 10 years for flexible pavements. Or, pooling these values for New Jersey pavements, maximum design values are 6.7 million EALs over a 13.3-year life. A terminal serviceability index of 2.5 was assumed.)

As the data given in Table 3 indicate, the 9,060 trucks ticketed annually for overweight violations were estimated by the model to cause 38,146 EALs of pavement damage. This corresponds to a 7.63 percent loss in pavement life. That is, of the 500,000 EALs designed to be exhausted in a 1-year period, 7.63 percent were illegally consumed by overweight trucks.

It may reasonably be argued that important bene-

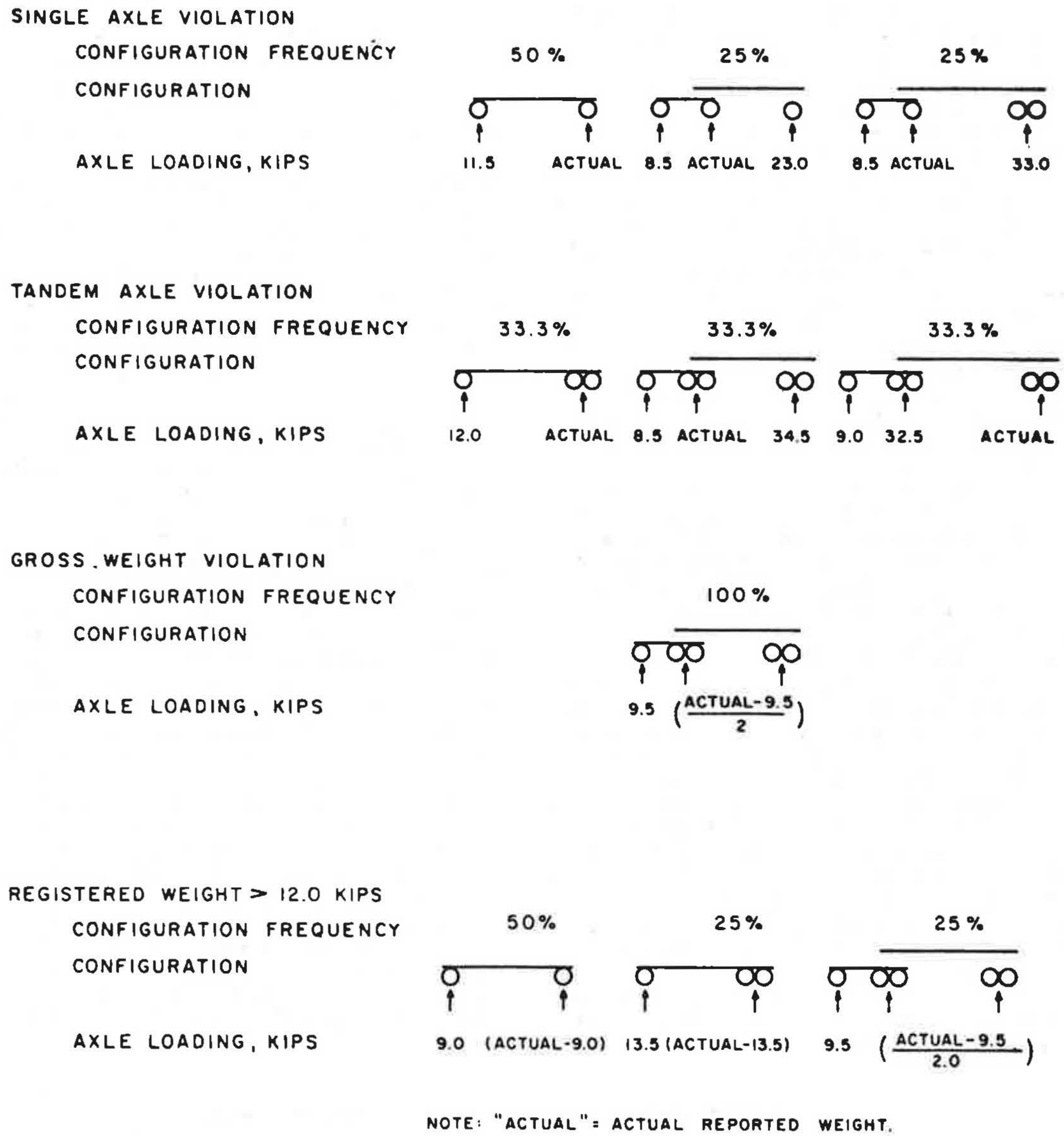

FIGURE 3 Selected truck configuration and axle loadings by violation type.

TABLE 3 Annual Pavement Serviceability Consumed by Known Overweight Trucks and by a Hypothetical Fleet of Legalized Trucks

Fleet	Trucks in Fleet	Gross Fleet Weight (kips)	Modeled 18-kip EAL	Modeled 18-kip EAL as a Percentage of Design
Actual	9,060	576,030	38,146	7.63
Legalized	10,190	607,560	30,869	6.17
Difference: (legalized minus actual)	+1,130	+31,530	-7,277	-1.46

Note: Additional trucks dispatched for all but registered-weight violations.

fits were derived from the transportation of the overweight cargos, although these cargos need not have been transported illegally. Therefore, to model the pavement damage that must be tolerated to maintain these same benefits, more trucks must be added to the traffic mix. These trucks would carry the excess loads of the overweight trucks so that all weights are reduced to the legal limits. The fleet of additional trucks was modeled as the required number of legal, fully loaded rigs the axle configurations of which were the same as the configurations of the trucks cited for being overweight.

The data in Table 3 indicate that an additional 1,130 trucks would be added to the traffic mix if the same loads were to be carried legally. Because each of these trucks would also introduce its tare weight, the pavement would be required to carry an additional 31,530 kips over a 1-year period. But, because each of the individual axle groupings would now carry less weight, the overall EAL loss would be only 6.17 percent per year of the intended design. In other words, assuming that the same amount of goods is hauled by either fleet, the net loss in service life attributable to detected overweight violations is 7.63 less 6.17 or approximately 1.5 percent.

ECONOMIC IMPACT MODEL

Although the quantified loss in pavement life is relatively small, capital and operating expenses associated with ownership of a pavement may be large enough to inflate the associated dollar loss beyond levels that should be reasonably tolerated. Therefore it is necessary to estimate the economic impact of this loss and determine whether the existing fine structure will generate sufficient revenue to cover it.

Two basically different methods have been proposed with which to estimate and apportion pavement-related costs. One computes the cost of the materials required to produce a pavement with the minimum structural number required to carry the designated loads. This approach would be suitable for analyses involving the capital expenditures associated with the construction of a new pavement but is considered inappropriate here. A second approach, which is more directly related to pavement maintenance, was used in this analysis. In this second approach, the cost of the several generations of overlays implicitly planned in a pavement's design is compared to the larger costs that will be incurred as the consequence of a premature loss of serviceability due to overweight trucks. That is, for the same time span, the overlay cost associated with the planned design loadings is compared to the total overlay cost associated with the unplanned, increased vehicle loadings. The present worth of the difference between these two costs is one measure of the economic damage done by overweight trucks. The basic concept underlying this approach is discussed in a recent paper (5) and is shown in Figure 4.

In New Jersey's overall roadway system, the population of existing pavements includes a broad range of ages. Some roads have been built recently, others are older, and some are 20 years old and older. A reasonable model of this roadway system must recognize that pavement failure and repair are a continuous process. If it is assumed that those pavements most needing attention receive it, it can be inferred that an approximately constant distribution of pavement ages exists and that the average of this distribution approaches a steady-state value representing the average remaining life of typical pavement. To simplify the model, all pavements are assumed to have the same value of remaining life. (Several numerical checks have shown that this produces essentially the same results as the more realistic but more complex model that uses a distribution of expected remaining life.)

Other factors that must be considered include interest and inflation rates, the average trip length of an overweight truck, and the total cost of a single overlay. At the time of this writing, interest and inflation rates are receding from their previous record levels and values of 8 and 5 percent, respectively, appear to be reasonable estimates. However, any attempt to project these levels into the future is risky at best so the analysis was run using both higher and lower values to determine the sensitivity of the outcome to these parameters.

Because New Jersey is about 50 mi wide and 150 mi long, trip lengths may range anywhere from short hauls of 10 mi or so to the length of the state. However, New Jersey has traditionally been regarded as a "corridor" state, which tends to suggest that longer trips are more common. Because the results are directly affected by the average trip length, values of 25, 50, and 100 mi have been used. And, because the analysis deals with the economic impact of rescheduling future overlays to an earlier date, all costs normally associated with a resurfacing contract must be accounted for.

These costs include engineering, traffic control, patching, resetting manholes, and so forth. A review of recent construction contracts in New Jersey indicates that a typical cost is about $10.00 per square yard. Also, in determining the number of square yards to be overlaid, it will be assumed that the typical pavement is two lanes (24 ft) wide.

The results of the analysis are given in Table 4. Given an average remaining pavement life of 10 years, an assumed typical trip length of 50 miles, and nominal interest and inflation rates of 8 percent and 5 percent, respectively, the economic impact of detected overweight violations is $46,549 per year. If additional trucks were dispatched to carry the excess loads, and none of these trucks were overweight, the annual cost in pavement serviceability would be $37,661. The net difference in this case is $8,888. Table 4 also gives the results of the sensitivity tests reflecting the uncertainty

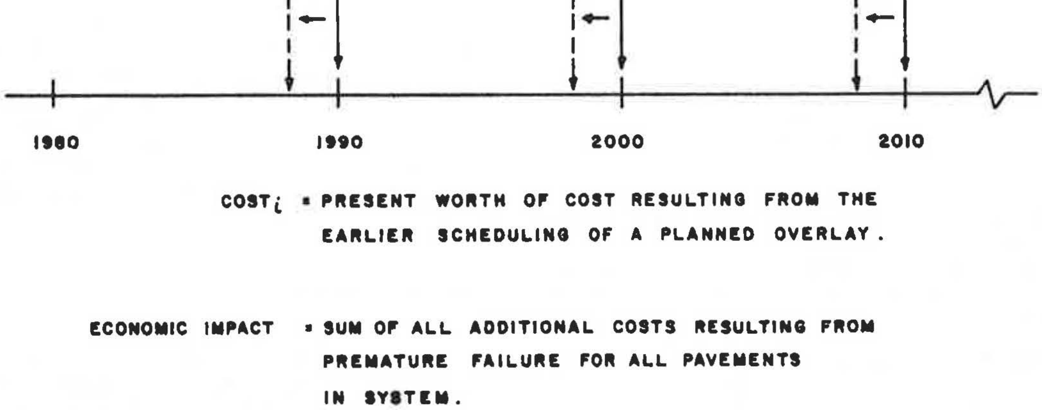

FIGURE 4 Concept on which economic impact is based.

TABLE 4 Annual Cost of Pavement Damage Attributable to Detected Overweight Trucks Under Steady-State Condition, 1983 Dollars

Average Remaining Life (yr)	Average Overweight Trip (mi)	Modeled Truck Fleet	Trucks Modeled	Interest and Inflation Rates (%)					
				5, 5	6, 5	7, 5	8,5	9,5	10, 5
5	25	Actual	9,060	26,855	26,855	26,834	26,795	26,737	26,662
		Legalized	10,190	21,732	21,730	21,712	21,679	21,630	21,568
	50	Actual	9,060	53,710	53,709	53,669	53,590	53,474	53,323
		Legalized	10,190	43,463	43,459	43,424	43,357	43,261	43,136
	100	Actual	9,060	107,420	107,418	107,338	107,180	106,949	106,646
		Legalized	10,190	86,926	86,919	86,848	86,715	86,522	86,271
10	25	Actual	9,060	26,855	25,612	24,419	23,275	22,178	21,128
		Legalized	10,190	21,732	20,724	19,757	18,830	17,942	17,092
	50	Actual	9,060	53,710	51,223	48,837	46,549	44,357	42,257
		Legalized	10,190	43,463	41,448	39,515	37,661	35,885	34,184
	100	Actual	9,060	107,420	102,446	97,674	93,099	88,714	84,514
		Legalized	10,190	86,926	82,896	79,029	75,322	71,769	68,367
15	25	Actual	9,060	26,855	24,426	22,220	20,217	18,397	16,744
		Legalized	10,190	21,732	19,765	17,979	16,356	14,883	13,545
	50	Actual	9,060	53,710	48,852	44,440	40,433	36,794	33,487
		Legalized	10,190	43,463	39,529	35,957	32,713	29,766	27,090
	100	Actual	9,060	107,420	97,704	88,881	80,867	73,588	66,975
		Legalized	10,190	86,926	79,059	71,914	65,426	59,532	54,179

of selected input variables. According to these tests, the previously calculated cost of $46,549 ranged from a low of $16,744 to a high of $107,420.

EXTRAPOLATION TO INCLUDE UNDETECTED VIOLATORS

If a considerable number of overweight violators remain undetected, it is of limited value to know the economic impact of only those that are detected. The quantified costs may be severely underestimated. Overweight trucks exact a toll in pavement life regardless of whether or not a citation is issued. But, as discussed in a previous section, it is difficult to obtain an unbiased glimpse of that particular segment of the overall truck population that has a decided incentive to remain undetected. Thus, if a glimpse of this segment is to be had, the price to be paid is reduced precision.

Two distinct approaches were attempted to estimate the magnitude of the factor used to multiply the costs presented in Table 4 so that the resultant product would also include the impact of undetected overweight violators. One approach is based on the ratios of summary statistics and the other on visual inspection of weight violation histograms. These two approaches produced similar results.

The estimation technique relying on ratios requires that the total number of truck trips be known. Recent loadometer studies in New Jersey suggest that 30 million annual truck trips may be a reasonable estimate. Three independent sources suggest that roughly 20 percent of these may be overweight. The first source is a bridge on Interstate 80 in Pennsylvania, just west of the New Jersey border, that was calibrated with strain gauges to monitor weights of five-axle trucks without driver awareness (6). This study concluded that approximately 20 percent of these trucks exceeded Pennsylvania's gross weight limits during the study period. An independent check of this 20 percent figure may be obtained by calculating the ratio of violators to trucks weighed in New Jersey using portable weigh scales. This ratio, for all violation types, is 0.174 or approximately 20 percent. And, finally, FHWA sources contacted personally indicate that 10 to 20 percent overweight trucks is a reasonable estimate on a national scale. Thus, to determine the approximate ratio of total weight violators to known weight violators, the estimated 30 million annual truck trips may be multiplied by 20 percent and divided by the roughly 10,000 known overweight trucks to obtain a factor of 600. If a 10 percent violation rate were assumed rather than 20 percent, the estimated factor would be 300.

A check on the reasonableness of this factor was performed by visually comparing the frequency histograms for weights on tandem axles as reported by the loadometer study and by the model based on state police data. In this comparison, the upper tails should (a) reasonably fit the body of the histogram and (b) be consistent with one another. Both of these criteria are met if the number of detected violators is multipled by a factor of approximately 400, as shown in Figure 5. Because the appropriate factor is estimated to be approximately the same by two independent criteria, the credibility of the estimate is enhanced. The appropriate multiplying factor was assumed to be 400 for the purposes of this study.

Returning to Table 4, a reasonable estimate of the total annual pavement damage done by all overweight violators is then 400 x $46,549 or approximately $19 million. This estimate could be as low as $7 million and as high as $43 million depending on the assumptions made regarding interest, inflation, the average remaining life of a pavement, and the average length of an overweight trip.

UNQUANTIFIED CONSIDERATIONS

One point estimate of the present worth of the pavement damage done by all overweight trucks in New Jersey is $19 million per year. The derivation leading to this estimate must be understood if a meaningful assessment of the implications arising from this figure is to be made. Pavement serviceability losses attributable to overweight trucks were quantified using the AASHTO EAL parameter and converted to a dollar value through economic formulas that calculate the cost of a premature maintenance expenditure at a future date. This procedure assumes that the only effect overweight trucks have on pavement's life is an increase in the utilization rate of the pavement's latent EALs. Bridge damage is not included in these costs. Unfortunately, at present there is no convenient way to estimate the damage done to bridges and there is concern that this might add significantly to the total costs.

It is possible that, in an extreme case, a single, excessively loaded truck may fracture a pavement and thereby drastically shorten its life.

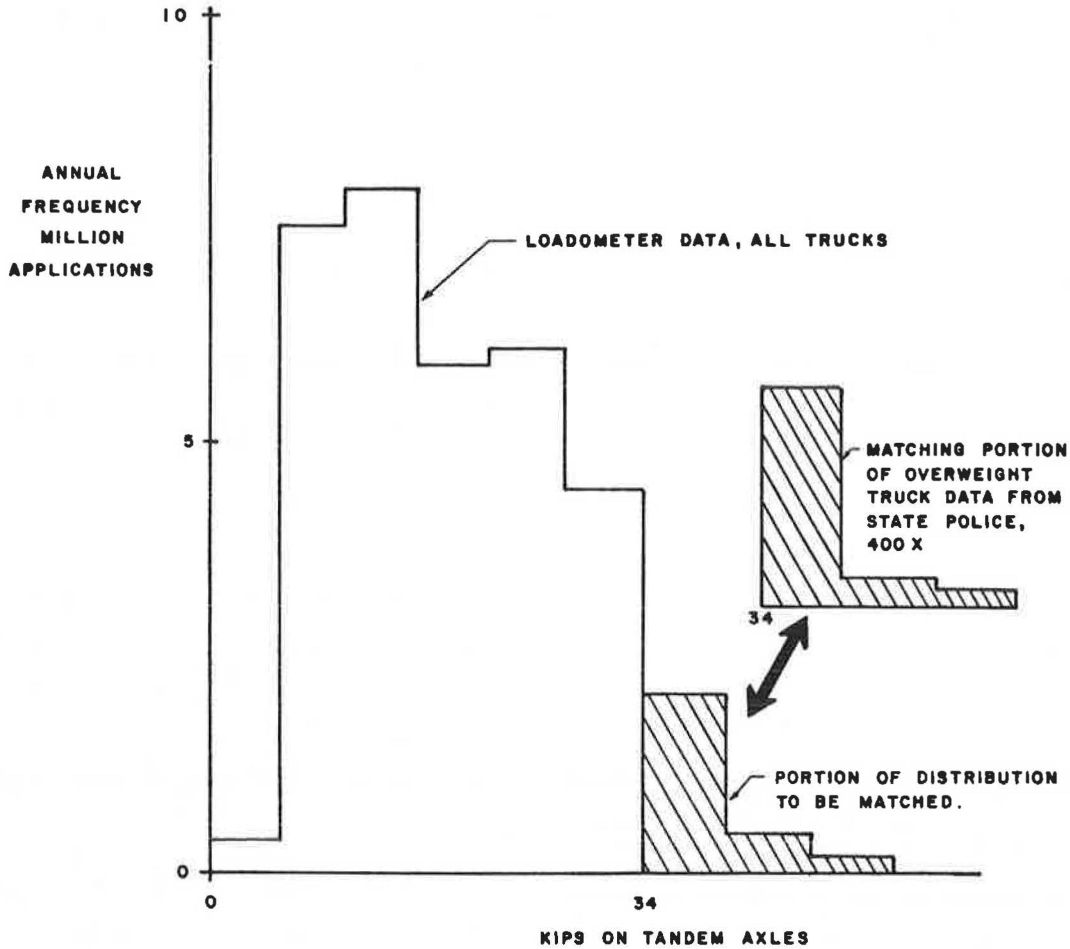

FIGURE 5 Frequency distribution of weights on tandem axles.

This would be more likely to occur on secondary roads where the pavement section is generally less strong. Although at least some of the overweight trucks must travel on secondary roads, it was judged unlikely that they would travel their entire (50-mi average length) trip on them. This would suggest that smaller portions of these roads may require excess weight-induced maintenance and that this maintenance may be less costly than assumed in the economic analysis. Nevertheless, this potential impact must be treated as an important unknown that could further increase the quantified costs.

The cost of enforcing the overweight statute cannot be overlooked. With the present level of enforcement, this cost was estimated to be $1.7 million per year (source: Division of State Police). It will undoubtedly increase if an improvement in the overweight detection rate is attempted.

This investigation focused on the primary economic considerations resulting from direct engineering analyses. Secondary economic effects were not investigated. Thus no adjustment were made to the revenue figures for the fuel taxes, toll road receipts, registration fees, and so forth that operators of overweight trucks pay. Similarly, overweight trucks were not charged for time lost due to increased traffic congestion, increased pollution, and other indirect considerations.

It was judged unnecessary to make an adjustment in the rate of pavement deterioration attributable to environmental considerations because, theoretically, this is a cost that is logically apportioned in full to all legitimate vehicles. Overweight charges were calculated as a differential from the established datum apportioned to all other vehicles. Thus, in large part, the interaction between overweight trucks and those environmental factors that affect cost considerations was screened from the analysis.

SUMMARY AND CONCLUSIONS

This study was undertaken to analyze the physical damage to pavements resulting from overweight trucks. To this end, two large samples were drawn from the population of known weight violators and, from these, specific truck characteristics (typical axle configurations, configuration frequencies, and typical axle loadings) were determined. This information was then coupled with characteristics of typical New Jersey pavements and, using the AASHTO EAL parameter, pavement serviceability was apportioned in a reasonable manner. Principles of engineering economics were then applied to quantify the magnitude of the associated monetary impact. These analyses led to the following conclusions:

1. Available data indicate that the pavement damage attributable to detected overweight trucks in New Jersey is relatively small, shortening the remaining pavement life by about 7.6 percent. If the same amount of goods was carried by an additional number of legally loaded trucks, the shortening of

life would be about 6.2 percent. The net shortening of life resulting from the trucks known to be operating in overweight is equal to the difference, or roughly 1.5 percent.

2. An analysis was done to assess the economic impact of these overweight violations. The shortening of average life results in an increased frequency of resurfacing that raises the overall costs of maintaining the pavement system at a serviceable level. However, as with the change in the average life expectancy, the increase in costs due to detected overweight trucks is relatively small and is overshadowed by the costs of the enforcement effort as a whole.

3. Therefore, with the present level of enforcement, mandatory off-loading may not be worthwhile because it affects only those violators who are caught. The most that would be gained were all of these violators off-loaded, even if this occurred at the trip origin, would be a savings in pavement life of about 1.5 percent, which corresponds to a cost savings of about $10,000 per year. In exchange, additional manpower would almost certainly be required and the highway agency would be exposed to a potentially increased liability for the welfare of the off-loaded goods. Thus the question is raised as to whether this enforcement practice is truly cost-effective. (An exception to this reasoning would be the case in which off-loading is done to avoid exceeding posted bridge load limits. Also unaddressed is the possible deterrent effect such a provision might have on undetected violators.)

4. Extrapolation of data to include undetected violators in New Jersey indicates that the total pavement damage attributable to all overweight trucks is considerable. One point estimate of the cost of this pavement damage is $19 million per year.

5. At the present level of enforcement, the fine structure that existed before September 1983 would generate about $1.1 million in revenue each year. This revenue, which is not sufficiently large to cover the costs of enforcement alone, is dwarfed by the extrapolated magnitude of total pavement damage. The discrepancy would be further accentuated if other, unquantified costs were also to be included.

6. On the basis of these findings, it is concluded that a substantial increase in the revenue generated by overweight trucks may be in order. This may be accomplished by increasing the present fine structure, the present level of enforcement, or both.

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