crease in fuel consumption on rough pavements reported here is considerably less than the increases reported in some earlier studies. But since the curve in Figure 5 is distinctly nonlinear over the possible range of roughness, comparisons such as this may be misleading. For example, assignment of an improper objective roughness level to Claffey's "badly broken and patched" surface could be of major consequence. Differences in objective roughness scales, as between SI and Zaniewski's quality index, could also be of major consequence. Therefore, comparisons of reported relations between fuel consumption and pavement roughness require great care.

CONCLUSIONS

Based on an analysis of data collected in this study, and within the limits implied or expressed, the following conclusions are made:

1. The effect of pavement roughness on automobile fuel consumption, because it is proportionately small, can be overwhelmed by the effect of more significant variables--e.g., travel speed, road gradient, driving habits, and wind velocity. In particular, wind can pose great difficulties in conducting field tests on fuel consumption. For this study, reliable data were obtained only during virtual dead-calm conditions.
2. To detect the relatively small variations in fuel consumption produced by pavement roughness, equipment capable of very accurate measurement is essential. The manual fuel meter developed for this study and described in this paper proved capable of measuring fuel consumption accurately to 1 mL, which for the 4000-ft test segments used here is considered minimum acceptable accuracy.
3. The collected data indicate that automobile fuel consumption increases as pavement roughness increases, where roughness is measured in terms of SI. Between the smoothest and roughest pavement included in this study (SIs of 4.4 and 0.9, respectively), the indicated increase was about 3 percent, which appears to be considerably less than has been reported by other investigators. However, since the relation between fuel consumption and pavement roughness determined in this study is distinctly nonlinear, comparison with results from other studies must be done with great caution.
4. Although the relation between fuel consumption and pavement roughness appears nonlinear over the range of roughness included in this study, for the pavements normally encountered on Wisconsin state trunk highways (SIs ranging from 4.5 to 1.5), the relation can be approximated by a straight line that has a slope of 0.000 187 9 gal/mile/SI. This study indicates that, for the conditions described here, an automobile traveling on a paved surface that has an SI of 1.5 consumes about 1.5 percent more fuel than it would consume traveling on a paved surface that has an SI of 4.5.
5. For the three automobiles used in this study, the relation between fuel consumption and pavement roughness was not an apparent function of vehicle size.

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Rational Seasonal Load Restrictions and Overload Permits

BILLY CONNOR

Seasonal load restrictions have been enforced in Alaska since the first paved road in 1950. The time frame and level of such restrictions have historically been based on the experience and judgment of maintenance personnel. This results in a lack of continuity from region to region. A rational load-restriction policy has been developed based on the load-damage relations on a pavement structure. Deflection data are used to monitor the strength of the embankment and thus to provide the information on which to base the time frame and level of restrictions. A policy on overweight-vehicle permits is presented based on the ability of the roadway system to carry the load and the load-damage relations. The policy uses the philosophy that the user pays for any damage in excess of that which would be incurred by legal loading.

The relation between vehicle weights and the performance of the pavement structure has been recognized for many years. Because of the large decrease in pavement life due to heavy vehicle weights and the rapid rise in maintenance costs, strict control of excessive truck weights has become imperative.

The problem of controlling excessive truck weights becomes crucial when the stress in the asphalt layer exceeds the tensile strength of the material. When this occurs, failure is immediate. Failure due to high tensile stress is not likely to happen under normal conditions. However, for highways in cold climates, this may well be the case if the pavement structure is weakened during the spring-thaw period. To protect these highways during the thaw-weakened period, a decision must be made concerning the level and duration of spring load restrictions.

In Alaska, as in most other states, such decisions have typically been made by maintenance engineers based on their experience and judgment. Studies based on deflection testing have shown that these decisions are sometimes inaccurate, which often results in premature pavement failure. In other cases, load restrictions have been imposed on roadway sections unnecessarily. A rational policy of seasonal load restrictions should be established to protect weakened roads. At the same time, the trucking industry should not be unduly burdened by unjustifiable load restrictions.

Unfortunately, the problem of excessive truck weight is not limited to spring-thaw periods. Too many of the trucks traveling the nation's highways exceed state weight limits. The key reasons generally cited are lack of enforcement and fines that are too small to be a deterrent. The cost and difficulty of obtaining overweight-vehicle permits vary greatly. In Alaska, as in many other states, the cost is based on administrative costs and not on the damage to the roadway. The damage to the roadway surface by overweight vehicles is borne by all road users (1).

EFFECTS OF WEIGHT ON PAVEMENT PERFORMANCE

The effect of axle weight on the performance of pavements has become a common topic of conversation among transportation engineers. Because of limited highway and airport funding, pavement management has become imperative. The primary aim of any pavement management method is to optimize the life of a pavement. Because the major factors affecting pavement life are the size and frequency of the loads imposed on the pavement structure, there is concern about the regulation of axle weights. Since the weight of the automobile is relatively small, the major portion of fatigue damage can be attributed to truck traffic. In fact, the proportion of pavement damage that can be directly attributed to trucks has been estimated to be as high as 90 percent (1).

Because heavy axle loads are responsible for such a large portion of the damage to the nation's highways, their effect on pavement performance must be understood. Many empirical and theoretical studies have been undertaken to describe these relations. Because of the importance of weight-damage relations in seasonal load restrictions and overweight-vehicle permit policies, a detailed discussion is given here.

Development of Weight-Damage Relations

Several studies have been undertaken to delineate the relations between load and damage on pavement structures. Most of these studies use an equivalent axle-load factor (F), which is defined as the ratio of the damage caused to a pavement by a single pass of a given vehicle to the damage caused by a single pass of a standard vehicle. This relation can be mathematically represented as follows (2):

$$F = D_x/D_s \tag{1}$$

where D_x is the damage caused by a single pass of a specified vehicle and D_s is the damage caused by a single pass of a standardized vehicle.

The American Association of State Highway Officials (AASHO) Road Test formula, which predicted this ratio, is

$$F = [(W_2 + 1)/(W_1 + 1)]^{4.79} \tag{2}$$

where W_2 is the axle weight of the vehicle in question (kips) and W_1 is the axle weight of the standard vehicle (kips).

Typically, a single-axle load of 18 000 lb is defined as a standard because it was the legal maximum load in most states at the time of the AASHO Road Test (1958-1960). A 33 000-lb tandem axle load is usually assumed to have an equivalency factor of 1.0. Figure 1 compares the equivalency factors derived from the AASHO Road Test with those from the Pennsylvania Department of Transportation (PennDOT) Test (3). The agreement is quite good.

Recently, computer modeling has made use of mechanistic analysis to predict load-related damage. Since tensile strain at the bottom of the pavement layer is usually associated with fatigue cracking, the following equation was developed by Deacon to compute equivalency factors (2):

$$F_i = (e_i/e_b)^c \tag{3}$$

where

F_i = equivalency factor,
e_i = maximum tensile strain due to the axle-load configuration,
e_b = maximum tensile strain due to an 18-kip single-axle load, and
c = 5.5.

Note that Equations 2 and 3 are similar; indeed, it has been shown that they compare favorably.

Multiple Axles

Most of the work in weight-damage studies has assumed single axles and tandem axles only. In 1979, Havens, Southgate, and Deen (3) used a modified Chevron N-Layer computer program to predict damage to pavement from multiple axles. The following conclusions were reached:

> For most highway vehicles, the deflections caused by a set of dual tires will be influenced by the dual tires on the opposite end of the axle. Similarly, the addition of another axle has a modifying influence on the deflection bowl of the single axle. In a three-axle group, maximum deflection will occur beneath the inner tire on the center axle. However, fourth and/or succeeding axles are located far enough from the "center" axle of the triaxle group as to have almost no effect on the magnitude of the deflection, but such additional axles do affect the horizontal dimension of the deflection bowl. Thus, the total load on a given group divided by the number of axles indicates that, for four or more axles, the total load can be increased by approximately 83.5 kN (18 800 lb) for each additional axle.

Figure 2 (3) shows the damage factors for various axle groupings based on the ratio of work strain at any given load to work strain for the 18-kip axle load. It is obvious that, whenever possible, the use of additional axles should be encouraged, especially in lieu of overweight permits.

Havens, Southgate, and Deen stress that the steering axle is a major source of damage. This damage has been shown to be especially large on pavements less than 2 in thick, such as those typically used in Alaska. The excess load on the steering axle should therefore be kept to a minimum.

Because damage caused by increased axle loadings is not linear, as has been shown, loads should be distributed over as many axles as practical. For example, 34 000 lb carried on a tandem axle may cause only approximately one-twentieth the damage of the same load carried on a single axle.

The steering-axle weight should be kept as low as practical because of the magnitude of the damage caused by heavy steering axles, especially on thin

Figure 1. Equivalency factors from AASHO and PennDOT Road Tests.

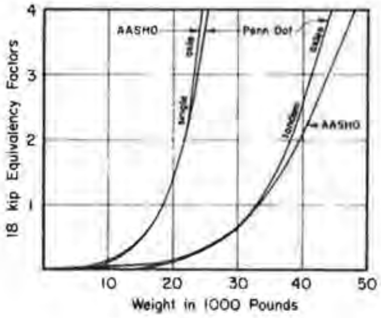
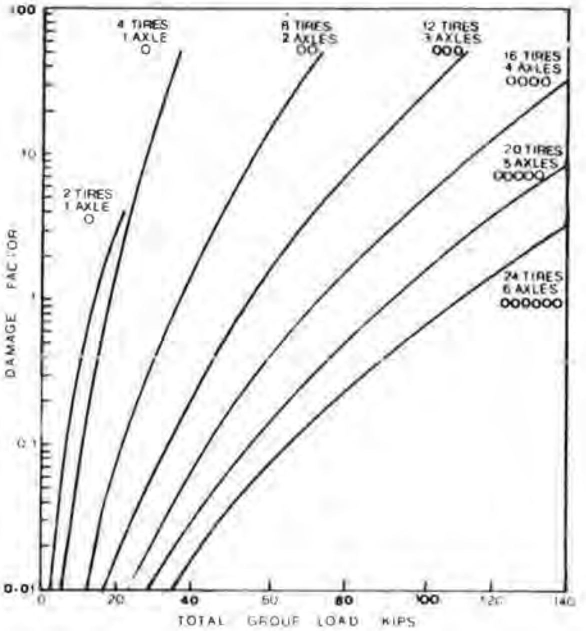


Figure 2. Damage factors for various weights on different axle configurations.



pavements. As Figure 2 shows, the damage factor for a legal 20 000-lb axle load on a two-tire front axle is twice as great as the same load on a four-tire rear axle. To be comparable, the legal front axle loading should be limited to 18 000 lb.

SPRING LOAD RESTRICTIONS

Structural damage done to pavements during spring thaw can result in very high maintenance costs. Spring load restrictions are often imposed during this period to limit damage to the roadway, which results in higher shipping charges to the public. When load restrictions reach a level of about 50 percent of the legal axle load, the route is effectively closed to most truck traffic. A balance must therefore be sought.

Most state agencies currently base the level and duration of seasonal load restrictions on the experience and judgment of maintenance engineers. However, quantitative methods of establishing load restrictions can and have been developed by using measurements of vertical pavement surface movements under a standard load, commonly termed "deflection test data". These methods allow each roadway section to be analyzed to minimize economic losses to all parties.

Current Seasonal Load-Limit Policy in Alaska

Currently, spring-thaw load limits are set by the regional maintenance engineer based on the engineer's judgment and experience. To an increasing extent, these decisions are influenced by deflection testing, most of which was accomplished for research programs. In the past two or three years, the use of deflection testing has become more common on urban routes; however, rural routes have no testing other than that performed by researchers.

Unfortunately, the maintenance engineer must give the trucking industry ample notice before setting load restrictions. Under the present policy, the maintenance engineer is forced either to wait until load restrictions are required before setting limits or to try to outguess the weather. However, as will be discussed later, this can be overcome by using deflection test histories for different roadway sections.

Current National Seasonal Load-Limit Practices

A review of the literature shows that 42 states and Canadian provinces experience seasonal freezing of roadways (4). Of these, 17 impose spring load restrictions. Ten states rely solely on experience and judgment, 5 use Benkelman deflection testing, 1 state uses plate load testing and the Benkelman beam, and 1 uses visual inspection and the Dynaflect deflection test method.

From the above summary, it is evident that procedures to establish spring-thaw load limits continue to be based on experience, even though quantitative procedures for assessing pavement behavior under load during the spring-thaw period have been available since the 1969 publication of NCHRP Report 76 (5). Most procedures use pavement deflection and/or curvature to determine the seasonal variations in pavement response. By using these procedures, seasonal load restrictions can be determined simply and economically.

Establishing a Spring Load-Limit Criterion

Hardcastle and Lottman (4) stated an appropriate philosophy for implementing load restrictions:

> The maximum axle load allowed on a pavement while it is in a spring-thaw weakened condition should be restricted to the load that produces the same horizontal tensile strain in the asphalt stabilized surface or base layer as is produced by the maximum axle load allowed on the pavement during the previous summer-fall (normal) period.

The accomplishment of this objective can be divided into three comprehensive tasks:

1. Define the pavement structure and determine its response to maximum legal axle loads during noncritical periods (summer and fall),
2. Determine the response of the pavement structure to loading during critical periods (spring thaw), and
3. Determine the maximum allowable axle load that can be applied during weakened periods without exceeding the horizontal tensile strains that would be induced by the maximum allowable axle loads during noncritical periods.

Determination of Pavement Response to Axle Loads

Tasks 1 and 2 require the determination of the response of the pavement structure to the axle loads imposed. This can be accomplished by determination of horizontal strains in the pavement but requires sophisticated computer modeling techniques and a considerable amount of data about the materials properties. These properties must be determined for the period in question.

Deflection data allow the in situ measurement of the pavement response without direct measurements of materials properties. Because of the ease with which deflection data can be obtained, deflection testing has become quite widespread. Three basic methods for obtaining deflection data are (a) static rebound (Benkelman beam), (b) vibratory response (Dynaflect and Road Rater), and (c) impact loading. Since the static-rebound methods have become standardized, the relations presented in this paper will be based on this method. Although correlations have been somewhat limited, standard practice has been to relate other methods to the static-rebound method.

Maximum Allowable Load During Critical Periods

Protection of roadways from premature failure is the end goal of a procedure for establishing load limits. However, this is no easy task. The maximum allowable axle load during critical periods must be determined to accomplish this task. If the philosophy adopted is that of limiting damage to what would normally be expected, the damage that could be expected both in the spring-thaw-weakened condition and in the summer-fall condition for various loads must be established.

As explained earlier, equivalency factors between different axle weights have been established by both theoretical and empirical approaches. Since the agreement between approaches has been good and since computers are not readily available to maintenance engineers, an empirical approach, based on deflection measurements, will be developed. Implied in this approach is the concept that the pavement deflection under a wheel load represents the strength of the pavement structure and that the strength of the pavement structure is directly related to pavement performance (4).

Figure 3 shows the relation between equivalent axle loads (EALs) per day, maximum annual deflection, and pavement life with no load limits as developed in Ontario, Canada (6). As expected, the pavement life decreases at a fixed number of EALs per day, commonly termed design traffic number (DTN), as the deflection increases. If, for example, the DTN is 800 EALs/day and the deflection level is 0.023 in, the life expectancy would be 20 years. Should the deflection level be increased to 0.031 in during the spring thawing period, the life expectancy would be reduced to 10 years. From Figure 4, a means of maintaining the 20-year design life at the 0.031-in deflection level would be to reduce the DTN to 390 EALs/day during spring thaw. Two methods are available to accomplish this: (a) reduce the number of axles that traverse the pavement or (b) reduce the maximum legal axle weight. The first method may cause hardships, since some vehicles will not be allowed to travel. The second method reduces for the freight industry the economic attractiveness of hauling over the highway system. When applied to spring load restrictions, the second method can be used most fairly and easily.

The reduced maximum axle load must now be determined. The ratio of the DTN at the higher deflection level to the desired deflection level is equal to the equivalency factor discussed earlier. Mathematically, this is represented as

$$F = \text{DTN (lower)}/\text{DTN (desired)} \qquad (4)$$

By equating this to the equivalency factor described by the AASHO Road Test, the following relation is formed:

$$\text{DTN (lower)}/\text{DTN (desired)} = [(W_2 + 1)/(W_1 + 1)]^{4.79} \qquad (5)$$

Rearranging the equation and solving for W_2,

$$W_2 = \left\{[\text{DTN (lower)}/\text{DTN (desired)}]^{0.209}\,(W_1 + 1)\right\} - 1 \qquad (6)$$

Continuing the previous example,

DTN (lower) = 390 EALs/day.
DTN (desired) = 800 EALs/day.
F = 390/800 = 0.49.
Assume that W_1 = 18 kips and $W_2 = (0.49)^{0.209}(19) - 1$ = 15.4 kips, the maximum allowable single-axle load.
Load restriction = 15.4/18, or 86 percent of the maximum legal axle load.

The technique used above allows the calculation of axle weights that will cause (on weaker pavements) the same damage as the heavier loads on stronger pavements. As has been shown, a single pass of a 15.4-kip load on a weakened pavement structure that has a Canadian Good Roads Association deflection of 0.031 in is equivalent to an 18-kip load on a pavement that deflects at 0.023 in.

This can be expanded to spring-thaw conditions. If a pavement has a summer deflection level of 0.023 in and the maximum legal axle weight is 18 kips, what load restriction should be imposed if the spring deflection increases to 0.031 in? If one applies the equal-damage philosophy, the maximum legal axle weight should be lowered to 15.4 kips, or 86 percent of the normal. The results of this procedure are graphically shown in Figure 4. The percentage reduction in axle weight can easily be determined by using Figure 4 and knowing the normal summer deflection level and the present deflection.

Because deflection data on Alaskan highways have been measured on only 150 miles, an alternative method of determining the acceptable deflection level must be provided until such data are available. Figure 5 is an adaptation from the California design procedure and shows the acceptable deflection levels for various pavement thicknesses and traffic indexes (TIs). If one knows the TI and the thickness of the constructed asphalt concrete pavement, the appropriate deflection level can be determined. For example, a route with a TI of 8 and a pavement thickness of 2 in would have an acceptable deflection of 0.034 in. Again, it is better to have measured the normal summer deflection.

To this point, the procedure implies that all roadways should be posted during spring thaw if the deflection level increases above the normal summer level. This is not practical nor necessarily desirable. It is therefore necessary to establish a procedure by which routes that do not need load restrictions can be determined.

Hardcastle and Lottman suggest that any route that has a fall deflection greater than 0.023 in should be posted in the spring. However, several cases have been observed in Alaska where sections had very low fall deflections and very high spring deflections. Obviously, in such instances, a fixed fall deflection criterion would be unacceptable.

An alternative procedure requires that the design deflection be used. If the spring deflection exceeds the design or acceptable deflection level, then load limits should be enforced. If not, the roadway need not be restricted. From Figure 5, the maximum allowable deflection level for a pavement thickness of 2 in and a TI of 8 would be 0.034 in. Should the measured spring deflection exceed 0.034 in, the load restriction applied would be determined by referring to Figure 4 and knowing the normal or acceptable deflection level.

Figure 3. Design deflection curve for various vehicle loadings.

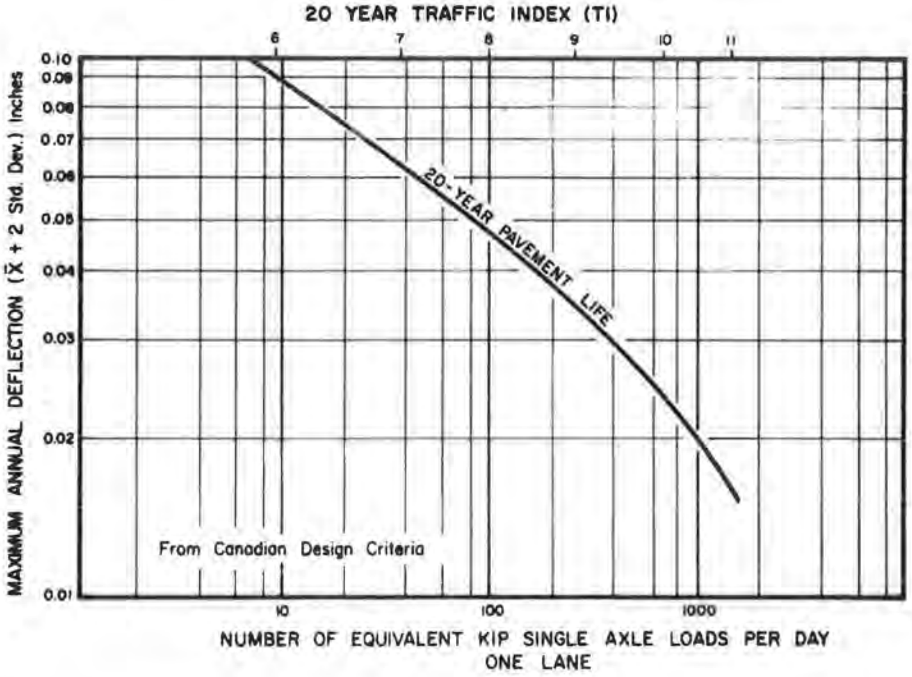


Figure 4. Load-limit percentages given measured deflections and normal summer deflection levels or acceptable deflection levels.

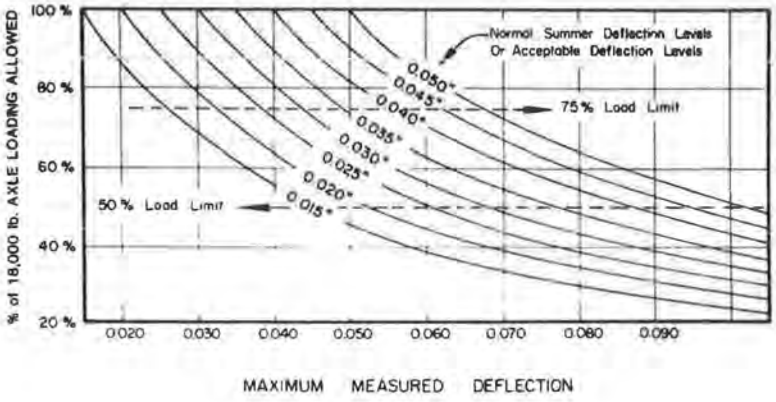


Figure 6 shows a flow chart that summarizes the procedure for establishing the level of spring load restriction. To illustrate its use, consider the following example.

The peak spring deflection of a roadway section has been measured to be 0.045 in. The pavement thickness is 2 in and the TI is 8. The normal summer deflection is unknown. Determine the level of load restriction that will be required. Since the normal summer deflection is unknown, the allowable deflection level for a TI of 8 and a pavement thickness of 2 in from Figure 6 is found to be 0.034 in. The measured peak spring deflection of 0.045 in is greater than the allowable deflection (0.034 in). Therefore, load restrictions will be required. From Figure 5, the level of restriction required for a peak deflection of 0.045 in and an allowable deflection of 0.034 in would be 80 percent.

Economic Impact of Load Restrictions on the Trucking Industry

Whenever load restrictions are imposed, the economic impact on the trucking industry is substantial. However, any additional damage done by trucks during this period is in effect subsidized by the general public. Because the general public is also the consumer, it ultimately pays for additional costs to the freight haulers. A balance must therefore be sought between the costs to the trucking industry and the costs of repairing and prematurely replacing roads.

Whenever load restrictions are in effect, trucking agencies can add additional axles, split loads, or divert shipments to rail or air carriers. Whenever additional axles are added, fuel consumption increases approximately 5 percent/axle, which adds about 4¢/mile to the cost. The cost of mounting an additional axle is about $50. These axles are often added during spring breakup, when loads that cannot be broken down must be hauled.

Shipment by rail is less expensive than trucking any time of the year. The major complaint is that it takes two or more days longer to move freight from Anchorage to Fairbanks by rail than by truck. For communities not in the rail belt, trucks are the only means of freight transport.

Air shipment is much too expensive for heavy freight movement. However, in some instances the cost may well be justified. Again, communities that do not have air strips capable of handling heavy aircraft must depend on trucks.

Figure 5. Acceptable deflection levels for various pavement thicknesses.

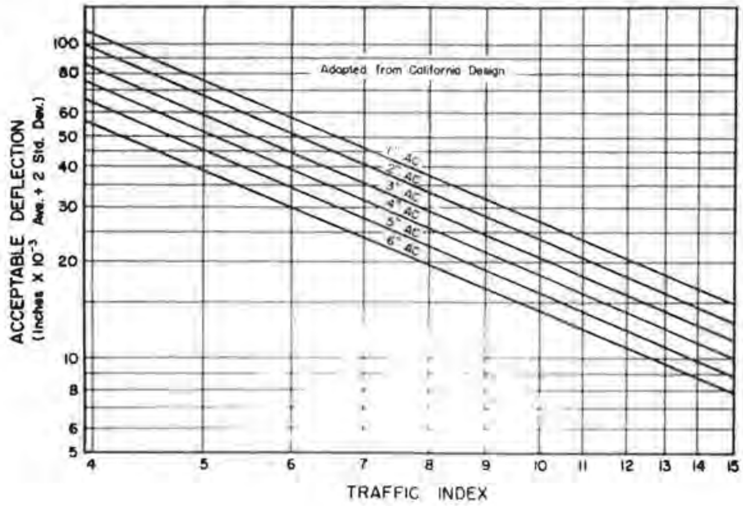
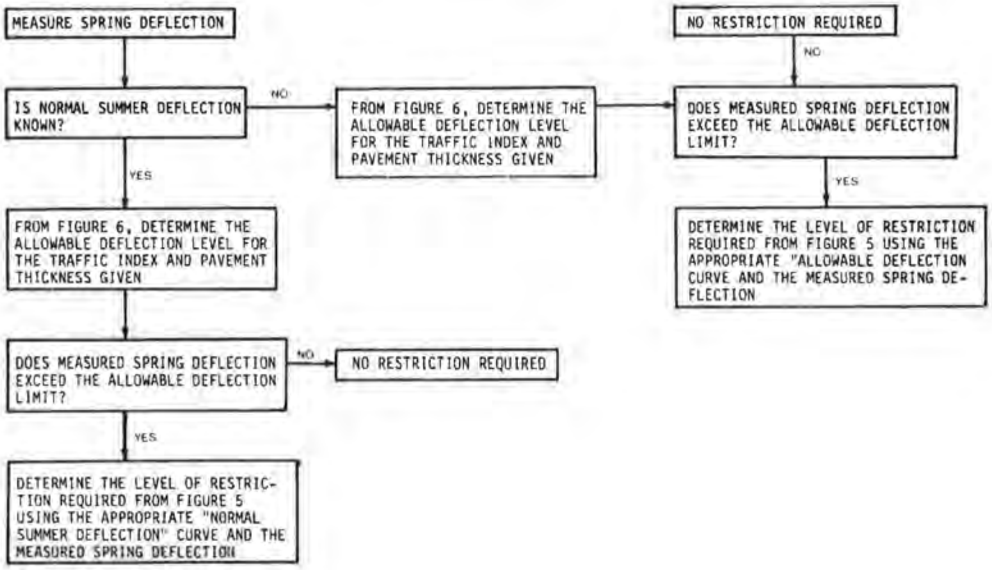


Figure 6. Flowchart for establishing spring load restrictions.



Interviews with several trucking firms operating within Alaska provided cost information for use in this study. These data are summarized below:

Area	Condition	Total Cost ($/ truck mile)
South of Fairbanks	Paved	1.62
North of Fairbanks	Gravel	2.56
Alcan Highway, Seattle to Fairbanks	Paved and unpaved	1.21

These costs include only operating costs--i.e., gas, oil, tires, and driver. The less tangible costs, such as safety, are not estimated here because no uniform method of estimation has been developed. When load restrictions are imposed, added trucking costs include the costs for additional trucks, trailers, and axles and the costs of transferring part of the load to the additional trailers. Figure 7 shows the relation between the percentage load restriction and payload for a 3-S2 tractor-trailer combination. Notice that, when the road is posted for 30 percent of legal axle load, no freight can be moved. The cost relations are shown in Figure 8. Understandably, most trucking agencies stop hauling when the load limits reach 50 percent because the cost becomes prohibitive. Similar plots for other truck types could easily be derived.

To amplify the magnitude of these costs to the trucking industry, consider the total daily cost increases incurred during the period when 75 percent axle restrictions are imposed. The average truck traffic on the Parks Highway for March and April of 1979 was about 140 trucks/day. Assuming that all of these trucks are traveling full, the increased cost would be $33 000/day on the Parks Highway alone. The costs for the major routes within Alaska are summarized in Table 1, where they average out to be $66/day/mile.

Cost to State If Load Restrictions Are Not Applied

Whenever a fully loaded truck travels a highway that is in a thaw-weakened condition, excessive damage occurs just as if it were overweight. The damage to the pavement can be estimated by redefining the "legal" load. For example, if restricting axle loads to 75 percent of the legal maximum is necessary to protect the pavement (using Equation 2), an 18-kip single axle would have an equivalency factor

Figure 7. Relation between payload and percentage restrictions for 3-S2 truck.

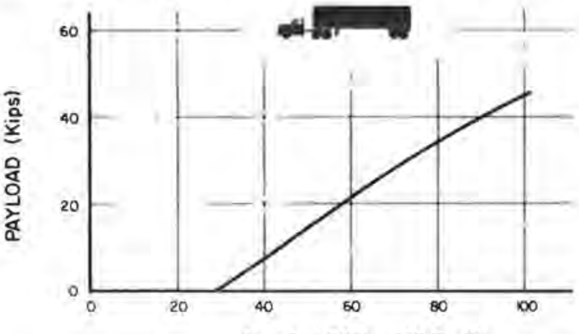
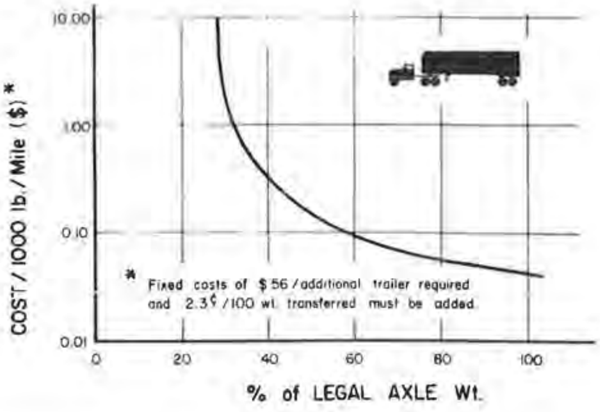


Figure 8. Cost per 1000 lb per mile with decreased axle weight for 3-S2 truck.



* Fixed costs of $56/additional trailer required and 2.3¢/100 wt. transferred must be added.

Table 1. Cost to trucking industry when 75 percent highway load restrictions are applied.

Route	Length (miles)	No. of Trucks per Day	Cost per Day ($000s)
Parks	360	140	33
Sterling	139	181	17
Seward	129	228	19
Glenn	189	107	13
Richardson			
Fairbanks-Delta Junction	97	68	4
Delta-Glennallen	151	35	4
Glennallen-Valdez	115	61	5
Alaska Highway			
Border-Tok	93	12	1
Tok-Delta	108	22	2
Tok Cutoff	125	22	2
Total			100

of 3.65. If a 50 percent restriction is required, the equivalency factor would be 21.64. If one knows the number of equivalent EALs, the cost to the state can be computed as follows.

Based on construction costs in interior Alaska, the present cost (1980) of a 2-in hot asphalt overlay 24 ft wide in Alaska is approximately $13/linear ft. A 2-in minimum overlay has been suggested in a recently completed study by McHattie, Connor, and Esch (7). The average peak deflection on the major routes within the state has been found to be 0.036. By using a 20-year design life and Figure 5, the current pavement cost to the state for each EAL-mile would be c = cost/mile/EAL life. From Figure 3, EAL life = 1 124 200. Therefore, c = 13(5280)/1 124 200 = $0.061/EAL-mile. A single pass of a legally loaded 3-S2 truck would cost $0.183/mile. If the same vehicle were to pass when 75 percent axle-load limits were required, the cost to the state would be $0.668/mile. The incremental cost would then be $0.485/mile/pass. Table 2 summarizes the cost to the state, which averages out to be $106/day/mile. The benefit/cost ratio for applying 75 percent load restrictions is then 1.6. It seems prudent, therefore, to apply load restrictions for the entire period required.

Sampling Frequency

Because of the expense involved and limited availability of personnel and equipment, testing an entire system annually would be impractical. A more practical method would be to determine those sections that are representative of a route through a deflection inventory. These sections could then be monitored during the spring thaw to determine when load restrictions should be applied. Care should be taken to select sections in each climatic region to ensure that load restrictions are not removed prematurely.

The inventory could also be used to establish the level of restriction required for each route. This would require management to establish what level of protection would be required for the routes in question. For example, it may be decided that load restrictions should be based on the deflection level below which 95 percent of all roadway sections fall.

Summary

Although the mechanism for thaw weakening is reasonably well understood, prediction of the magnitude and the time frame still must be measured in the field if accurate information is required. The use of deflection data allows an in situ measurement of the strength of the pavement structure without direct measurements of materials properties.

Relations between deflection levels and pavement life have been developed by a number of agencies. By combining these relations with the weight-damage relations found in the AASHO Road Test, the level of restriction can be ascertained. The underlying philosophy behind this determination is that damage allowed during the weakened period should be no more than the damage that would have occurred during the normal summer months.

By monitoring the deflection levels of carefully selected roadway sections, the time frame for load restrictions can easily be determined. Since the benefit/cost ratio is in favor of applying load restrictions, it is suggested that load restrictions should be maintained until it has been determined that the embankment has regained its strength. Since trucking agencies know within a few weeks the time when load restrictions will be enforced, they should be encouraged to schedule around them.

OVERWEIGHT-VEHICLE POLICIES

Although it is recognized that overweight vehicles are necessary, they must be closely regulated to prevent pavement damage. Nationally, it has been found that illegally overloaded vehicles travel the highways with little fear of enforcement (1). As a result, pavement life is being drastically reduced without compensation to the state governments. This requires not only effective enforcement but also a fair permit policy.

Any good permit policy should have three basic qualities:

1. It must strongly encourage legal loads whenever possible.

Table 2. Cost to state when 75 percent highway load restrictions are not applied.

Route	Length (miles)	No. of Trucks per Day	Cost per Day ($000s)
Parks	360	140	30.6
Sterling	139	181	32.1
Seward	129	228	37.5
Glenn	189	107	25.8
Richardson			
Fairbanks-Delta Junction	97	68	8.4
Delta-Glennallen	151	35	6.7
Glennallen-Valdez	115	61	9.0
Alaska Highway			
Border-Tok	93	12	1.4
Tok-Delta	108	22	3.0
Tok Cutoff	125	22	3.5
Total			158.0

2. Enforcement must be adequate to discourage movement of overweight loads without a permit.

3. The fines must be sufficiently large to reduce the economic attractiveness of avoiding permits.

Although there is little disagreement on the first requirement, lack of enforcement, low permit costs, and inadequate fines have been cited as primary reasons why so many overweight vehicles are operating on the nation's highways.

The overweight-vehicle policy described in this paper is based on the "user pays" philosophy. The permit cost is based on the estimated cost to the state for the overweight vehicle, including costs for pavement damage and administrative costs. The economic evaluation of whether to break the load down, add more axles, or pay for overweight loads is borne by the trucking company.

Current Alaska Policy on Overweight Vehicles

Under Alaska statutes (Section 19.10.060), the Commissioner of Transportation and Public Facilities is authorized to regulate the maximum size and weight of all vehicle operations on highways under his jurisdiction. The Alaska Administrative Code (17 AAC 25.0) stipulates the maximum vehicle weights and dimensions (7). This section also states that "Police officers or specifically authorized employees of the Department of Highways are delegated the authority to enforce these regulations."

The maximum axle loadings are given below:

Axle No. or Group	Maximum Weight (lb)	Minimum Axle Spacing (ft)
Single	20 000	10.0
2-axle tandem	34 000	3.5
3-axle tandem	42 000	3.5
4-axle tandem	50 000	3.5

The maximum gross vehicle weights are determined by the following equation:

$$W = 500 \{[LN/(N - 1)] + 12N + 36\} \tag{7}$$

where

W = maximum gross vehicle weight to the nearest 500 lb,
L = distance between the extreme axles (ft), and
N = number of axles.

The weight on any tire may not exceed 500 lb per inch of tire width.

The maximum single-trip permit limits that may be issued by the district permit offices are given below:

Axle No. or Group	Maximum Weight (lb)
Single	30 000
2-axle tandem	50 000
3-axle tandem	60 000
4-axle tandem	70 000

Tire loading is 750 lb/in, and gross vehicle weight (GVW) is 150 000 lb. Maximum GVW is 25 percent above the lowest posted weight limit on bridges.

For overweight-vehicle permits that exceed the values in Table 1, approval is required by the Department of Public Safety through the State Permit Officer. There is no mention of designating routes that may be used. The fee schedule for overweight-vehicle permits is given below:

Category	Fee ($)
Single trip of 0-99 miles; less than 150 000 lb GVW	10
For 30-day permits; not to exceed 15 percent over legal GVW	25
Single trip of 100 miles or more; less than 150 000 lb GVW	25
Single trip of 0-99 miles; for GVW of 150 000 lb or more	25
Single trip of 100 miles or more; for GVW of 150 000 lb or more	50

The total permit fee charged for any permit shall be the sum of the oversize and overweight fees as required.

Overweight-Vehicle Policies of Other States

A review of the overweight-vehicle policies of other states showed a wide variety of permit schedules. The policies can be summarized as follows: Eleven states have free permits, 22 have fixed fees, and 17 have permit fees based on excess weight (4). Of the 17 states that have graduated fees based on excess weight, 6 vary the fees with both excess weight and mileage.

Many philosophies exist concerning overweight-vehicle policies. If overweight loads are considered a normal part of a roadway's function, then permits may be free. Other states feel that the permit cost should pay for the administration, usually $5 to $10. If it is felt that the cost of the damage incurred should be borne by the hauler, the cost will probably be based on weight and distance moved. Still others feel that permit operations should yield revenue, in which cases the fees may be quite high.

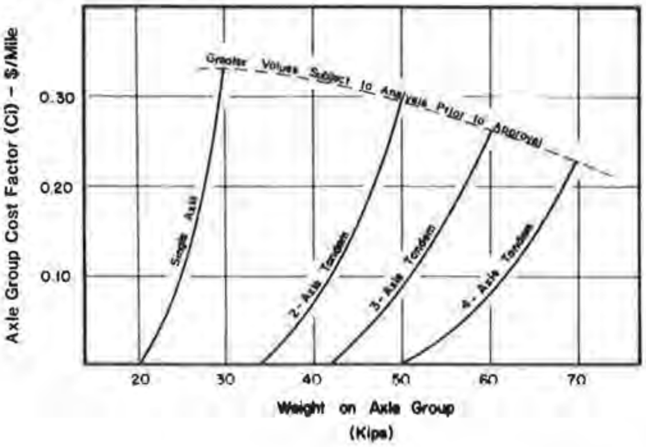
There is, however, a general consensus that permits should be issued only when (a) the load is not readily reduced, (b) there exists no other reasonable alternative mode of transportation that will not be excessively costly, (c) a reasonably large sector of the economy will benefit, or (d) damage to the pavement structure will not likely be any greater than any normally permitted moves.

Enforcement varies from almost nonexistent to very strict, as do the fines that are assessed. Legal weights vary widely from state to state, which causes problems with the interstate trucking industry. In some states, the legal load varies between Interstate and state highways, and this causes further confusion. Because of the confusion caused by such wide variation, every study reviewed recommended uniformity of legal weights and permit policies.

Rational Overweight-Vehicle Policy

Whenever an overweight vehicle passes over a roadway

Figure 9. Cost per axle mile for overweight-vehicle permits.



section, damage is done to the surface that exceeds the damage that has, in principle, been paid for in fuel and licensing taxes. If the owner of the vehicle is not charged for this excess damage, then he or she is in effect being subsidized by all the users of the roadway network. It seems reasonable, therefore, to base permit costs on this excess damage.

As was shown earlier, the average cost per EAL-mile within Alaska is approximately $0.06. By using equivalency factors, the excess damage for any truck can be determined in equivalent EALs. By combining these two factors, the incremental cost to the state of an overweight axle group can be determined by the resulting equation:

$$c_i [(W_{1+1}/W_{2+1})^{4.79} - 1]\, k \qquad (8)$$

where

c_i = incremental cost for a specified axle group per mile of travel,
W_1 = weight of the specified axle group (kips),
W_2 = legal weight of the axle group (kips), and
k = \$0.06 (cost/EAL-mile).

By summing the cost of all axle groups and multiplying times the distance, the permit fee can be determined as follows:

$$P_c = \sum_{i=1}^{n} (c_i\, d) + A_c \qquad (9)$$

where

P_c = permit cost,
n = number of axle groups,
d = distance traveled (miles), and
A_c = administrative cost.

The administrative cost may include bridge structural analysis and, in some cases, even pavement structural analysis. Because there is an upper limit to the load a pavement structure can tolerate without exceeding its fatigue strength, it is suggested that axle groups that have an equivalency factor greater than 6 be referred to the maintenance engineer or other persons in authority for approval.

Figure 9 graphically shows Equation 9 for various axle groups. To illustrate the use of Figure 9, consider the following example.

A permit is requested for a 3-S2 commercial vehicle with the following axle loadings: front axle, 18 000 lb; drive axles, 47 000 lb; and trailer axles, 50 000 lb. The load will be moved from Anchorage to Fairbanks (360 miles). Determine the permit cost, assuming an administrative cost of $25.00. From Figure 9, the cost per mile for each axle group is as follows:

Axle Group	Cost per Mile ($)
Front axle	0.00
Drive axles	0.21
Trailer axles	0.30
Total	0.51

From Equation 9, P_c = \$0.51 (360) + 25 = \$208.60.

This seems like a fairly high permit cost, but remember that, by using three-axle tandems, the permit can be avoided.

Summary

The overweight-vehicle policy suggested in this report adopts a "pay-as-you-go" philosophy. By using a current overlay cost of $13/linear ft of two-lane highway and the deflection-life curves developed in Ontario, a cost of $0.06/EAL-mile can be derived. By relating this cost to the weight-damage relations developed in the AASHO Road Test, a cost per mile permit cost can be computed. The resulting costs are shown in Figure 9.

Of course, if the system is to work, enforcement will be a key factor. For this reason, enforcement will need to be strengthened.

CONCLUSIONS

Seasonal Load Restrictions

1. A rational method of establishing load restrictions has been developed in this paper based on deflection data. It is recommended that Figure 4 be used in establishing load restrictions in Alaska.
2. Since extensive deflection data are required to determine the level of restriction, a deflection inventory is desirable. This inventory could also be used to predetermine problem areas to be monitored during the spring-thaw period to establish the time frame for load restrictions.
3. Monitoring of thaw depths can be used to determine when to begin deflection testing.
4. It has been shown that load restrictions are justified, since costs of damage to pavement will exceed the additional shipping costs during the restricted period. They should therefore be posted as long as required based on deflection testing.

Policy on Overweight-Vehicle Permits

1. Weight-damage relations dictate that overweight vehicles must be controlled to prevent unnecessary reductions in pavement life.
2. In order to recover the cost to the state for damage caused by overweight vehicles, it is recommended that permit fees be based on EAL-miles traveled in excess of legal loads plus a fixed cost for administration.
3. Whenever possible, additional axles should be required to avoid overweight vehicles.
4. For obvious reasons, no overweight-vehicle permits should be issued during the thaw-weakened period.

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State-Level Pavement Monitoring Program

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A long-term pavement monitoring program consists of the identification of specific data elements to collect, their measurement (including equipment), the sampling frequency both over time and within a pavement network and project, the efficient storage and retrieval of large amounts of data, its analysis and evaluation, and the use of the data in daily policy-level decisions and project programming. This paper describes (a) data needs for state-level management, planning, and design functions; (b) temporary data-collection activities by various states; (c) sampling strategies and data-processing strategies; and (d) key issues and problems to be considered in planning a long-term monitoring program.

There are three levels of pavement data monitoring. They correspond to three principal activities in the process of managing a state pavement network. State program management is concerned with overall planning, budgeting, and the equitable distribution of funding to political subdivisions of the state. It also includes special case studies and research needs, such as for cost allocation and improvement of design procedures. State project programming is concerned with selecting specific projects for an annual maintenance and rehabilitation program as well as for development of a projected future work plan. Project design is concerned with selecting the proper materials, layer thicknesses, and treatments for a specific project. Because the latter activity occurs on a project-by-project basis, it is not usually considered as part of a state's long-term monitoring program and will not be considered further here.

Long-term pavement data monitoring serves several important functions in state program management:

1. It provides current information on pavement condition and documents performance history on all functional systems for administrative, planning, operational, and research purposes.
2. It provides data for the projection of future funding requirements for various possible scenarios, including (a) keeping the pavement network in its current condition, (b) improving the condition of pavements on selected road networks, (c) determining the impact on network condition of a budget cut, and (d) keeping the pavement network condition stable in the event of changes in legal sizes and weights of trucks.
3. It provides accurate information to the legislature on current pavement conditions, costs, and accidents.
4. It provides information for the equitable allocation of funds to all subdivisions of the state weighted by the traffic, functional class, and occasionally the economic impact of specific road networks such as those used for hauling important products and commodities.
5. It provides information for a variety of special needs, such as studies of cost allocation or truck weight, requests from the public, state and national research projects, and data for use on the national level by the Federal Highway Administration (FHWA).

Long-term data monitoring assists in project programming in the following ways:

1. The determination of current condition and other information about specific sections of pavement to allow prioritization of and estimation of costs for required maintenance or rehabilitation and
2. The collection of condition and other data on a sufficient number of randomly sampled sections of pavement to provide the estimates and special studies that are required for state program management.

These multiple uses of a monitoring system require several types of information to be gathered and to be updated frequently. The data need to be gathered efficiently, by using sampling techniques both in time and along the length of various functional classes of highways. The purpose of sampling is to reduce to a minimum the effort that is required to collect the data. Although sampling is an essential element of a long-term monitoring program,