Axle Load Limits in Ontario: Long-Term Analysis

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ABSTRACT

Overloaded axles contribute significantly to the deterioration of road structures. Protection against severe pavement deterioration is provided in most jurisdictions by limiting permissible axle loads for commercial traffic. Within most provincial jurisdictions in Canada, axle load limits have been set arbitrarily with little reference to economic viability. In practice, axle load limits have been established from past experience based essentially on two conditions: (a) the need to maintain a reasonable level of serviceability on the road network and (b) available monies for annual rehabilitation and maintenance programs. The financing of rehabilitation and maintenance programs is supported from general revenues for each jurisdiction, and this allocation of funds may have little relevance to the incidence of costs and benefits to users of the road system or to the responsible transportation agency. In this study two actual axle load distributions are investigated to assess the effects of changing the axle load limits on transportation costs. These costs include pavement rehabilitation and maintenance and commercial and noncommercial vehicle operating expenditures. In Ontario the vehicle operating costs for commercial traffic are the dominant cost component that influences the economic viability of axle load limits. The increased operating costs of noncommercial traffic from reduced pavement serviceability appear to mitigate against increases in the maximum allowable axle load. Furthermore, long-term changes in truck fleet composition, resulting in a more efficient distribution of axle loads, may produce conditions under which higher axle load limits are economically justified.

Most jurisdictions provide protection against severe road surface deterioration by enacting legislation that limits permissible axle loads. These limits are established in most cases with little reference to general economic viability, and they remain both arbitrary and inconsistent across jurisdictional boundaries. A recent study by the Transportation Research board (1) suggests that failure to adopt consistent limits among states in the United Stated has imposed additional costs on both trucking operations and road administration. As noted by Connor (2) the situation is rendered difficult by divergent jurisdictional requirements that may affect the incidence of costs and benefits that result from different axle load limits in different environments. For example, in northern regions where subgrade strength may be reduced by severe freeze-thaw action, axle load limits are more critical in maintaining road serviceability than in a southern environment where seasonal variations are not as extreme. In Canada jurisdictional requirements and inconsistent economic guidelines have given rise to a wide range of provincial axle load limits.

In Ontario load restrictions were first applied in 1916 when single axle loads were limited to a maximum of 9 kips. Since then various attempts have been made by the Ontario Ministry of Transportation and Communication (MTC) to study the benefits and costs of various allowable load levels. In response to these studies, year-round limits have been systematically increased throughout this period. In 1961 the single axle load limit was set at 18 kips. A study conducted in 1966 by the Ontario Department of Economics and Development, quoted by Armstrong et al. (3), concluded that reduced vehicle operating costs for trucks amount to less than 4 percent of the cost of upgrading the road network to allow for maximum axle loads of 20 kips. Despite this finding, the maximum single axle load was again raised to kips in 1968. In this paper an attempt is made to assess the short-run and long-run economic consequences of this increase.

In this study economically viable axle load limits are established when the savings from reduced pavement deterioration and enhanced serviceability, which are realized by the road administration and by noncommercial traffic, are offset by additional costs to truck operators from reduced vehicle utilization. The basic objective of this paper is to assess the economic viability of increasing axle load limits from 18 kips (8.2 tons) to 20 kips (9.2 tons). Ontario axle load distributions for 1967 and 1981 are used to monitor the expected traffic responses to these changes.

The changes in axle loads before and after the introduction of new axle limits are assessed in terms of observed 1967 and 1981 load distributions. This approach is a significant departure from previous work in this area. In most studies to date, for example work by MacLeod et al. (4), observed axle load distributions are obtained for the base year conditions. Changes in these distributions for the horizon year are based on the application of exogenous elasticities to the base year profiles. The horizon year axle load distributions remain somewhat speculative because they depend on the accuracy of the unobserved arc elasticities.

The 1967 axle load distribution in this study is obtained from a random sample of 6,700 trucks weighed at various points along the 401 expressway in Ontario. Some of the results of this survey are documented in Armstrong et al. (3). The horizon year 1981 truck loadings are obtained from a sample of vehicles that were monitored at the MTC weigh-in-

motion scale located on the eastbound approach of the 401 expressway near Whitby. Both surveys were conducted during the summer.

In general, the framework introduced in this paper should provide economically effective guidelines for establishing maximum single axle load restrictions in most jurisdictions where traffic composition and environmental factors are similar to those in Ontario.

PROCEDURE FOR ESTIMATING AXLE LOAD RESPONSES

In 1967 a survey of 6,700 trucks was conducted in Ontario to determine gross vehicle weights and axle load distributions by vehicle type. Some of the results of this survey are documented by Armstrong et al. (3). Figure 1 shows the distribution of axle weights from the 1967 truck sample for three types of axles: single, tandem, and tri-axle combinations. Given a single axle load limit of 18 kips, these distributions suggest a significant number of overload axles or violators in the traffic stream. As noted by Armstrong et al. (3):

> Though certain instances of pavement deterioration due to excess loads had occurred, undue and widespread damage was not being caused by the regime of vehicle axle and gross weights which was actually using the highways. This confirmed other studies indicating that pavements might tolerate greater axle loads.

Table 1 gives a summary of the truck axle weight distribution from Figure 1 for this 1967 sample. The daily gross vehicle weight was estimated as 251,417 kips. All single, tandem, and tri-axle combinations were assumed to carry empty vehicle weight components of 2.5, 5.0, and 7.5 kips per combination, respectively. This produced a daily empty loading for the sample truck fleet of 46,209 kips and a payload of 205,208 kips per day (or approximately 72 x 10^6 kips per year).

Load equivalency factors from Figure 2 were applied to the 1967 axle load distribution to yield the equivalent single axle damage units for each gross vehicle weight interval. These damage estimates are summarized in Table 2. The 1967 sample truck fleet produced 12,328 equivalent damage units (DUs) per day or 4.5 x 10^6 DUs for the entire year, neglecting seasonal load variations.

The DU is a standard unit that reflects the damage caused by the passage of a standard 18-kip single axle. One of the most common methods that relates pavement life to standard axle passes or DUs is provided by the AASHO Road Test (5) relationship. This is shown in Figure 3. The structural number

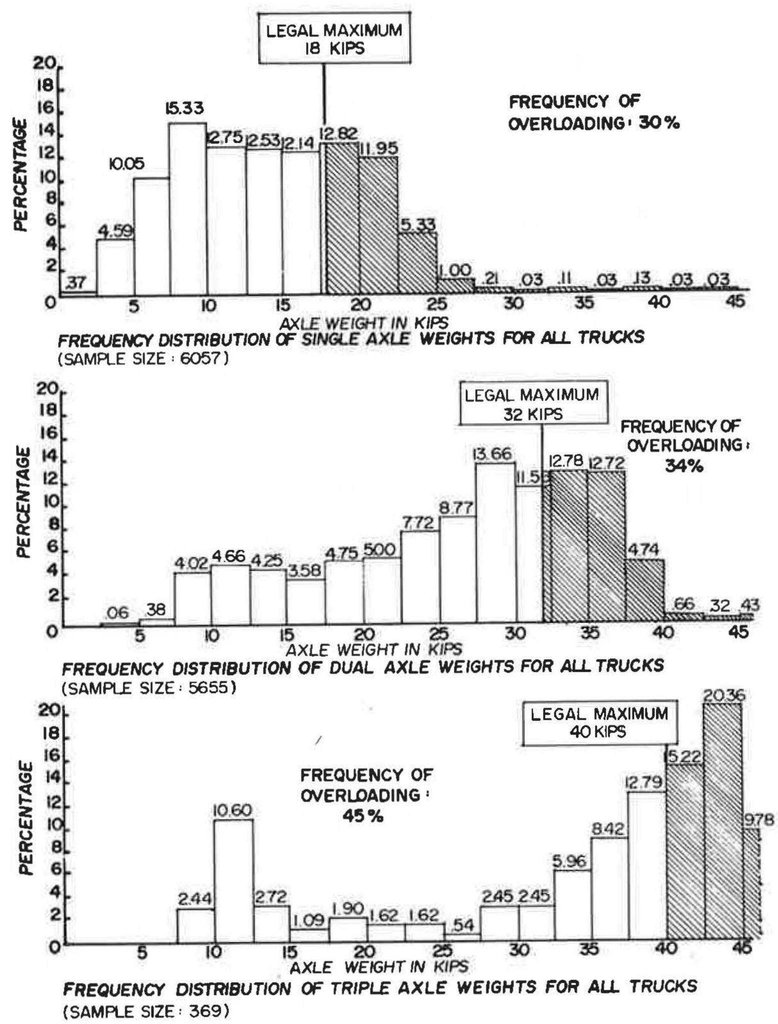

FIGURE 1 Selected data from 1967 truck survey.

TABLE 1 Truck Axle Weight Distribution, 1967

	Single Axles (50%)			Tandem Axles (47%)			Tridem Axles (3%)		
	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)
0-5	5.0	300	750.0	0.1	3	7.5	0.0	0	.0
5-10	25.5	1545	11587.5	4.4	250	1875.0	2.4	9	67.5
10-15	25.2	1527	19087.5	8.9	506	6325.0	13.3	48	600.0
15-20	24.9	1508	26390.0	8.3	472	8260.0	3.0	10	175.0
20-25	17.8	1077	24232.5	12.6	722	16245.0	3.3	12	270.0
25-30	1.2	73	2007.5	22.2	1270	34925.0	3.0	11	302.5
30-35	0.2	11	357.5	24.6	1410	45825.0	8.4	30	975.0
35-40	0.1	8	300.5	17.5	991	37162.5	21.2	77	2887.5
40-45	0.1	4	170.0	1.4	80	3400.0	35.6	129	5482.5
45+	0.0	0	0.0	0.0	0	0.0	9.8	35	1750.0
	100.0	6053	84882.5	100.0	5704	154024.5	100.0	361	12510.5

Note: Daily number of axles = 12,118 kips (payload plus vehicles); gross daily weight = 251,417 kips; vehicle weight (empty) = 46,209 kips (all truck types); daily payload = 205,208 kips; and annual payload = 72,000,000 kips.

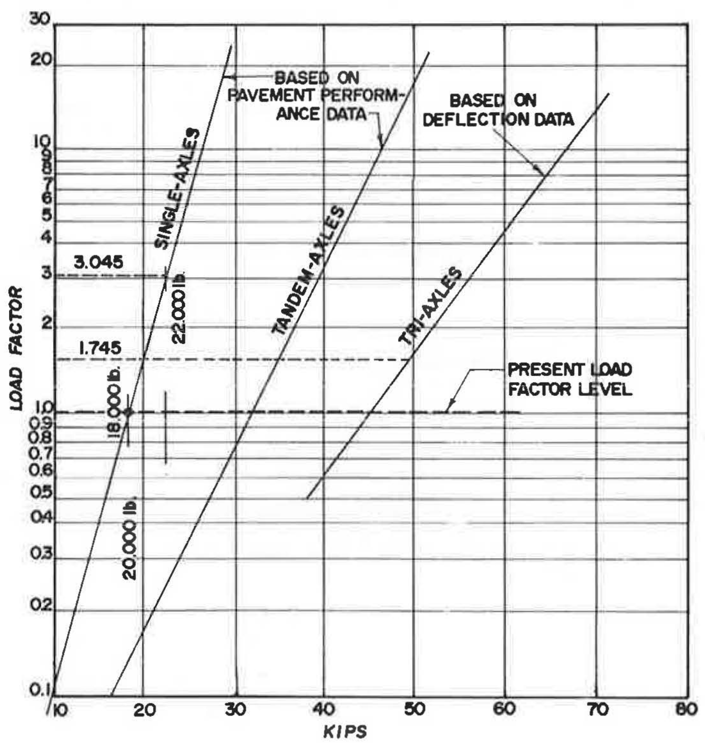

FIGURE 2 Load equivalency factors and axle load equivalents for flexible pavements, after Armstrong et al. (3).

TABLE 2 Damage Units for 1967 Truck Axle Loads

	Single Axles			Tandem Axles			Tridem Axles		
Weight (kips)	Load Factor	No. Axles	Equivalent DU (18 kips)	Load Factor	No. Axles	Equivalent DU (32 kips)	Load Factor	No. Axles	Equivalent DU (44 kips)
0-5	0.05	300	15	0.05	3	0	0.05	0	0
5-10	0.10	1545	155	0.05	250	13	0.05	9	1
10-15	0.15	1527	229	0.10	506	51	0.05	48	2
15-20	1.00	1508	1500	0.15	472	71	0.05	10	1
20-25	3.05	1077	3285	0.20	722	144	0.15	12	2
25-30	10.00	73	730	0.40	1270	508	0.20	11	2
30-35	25.00	11	275	1.00	1410	1410	0.30	30	10
35-40	40.00	8	320	2.80	991	2775	0.50	77	39
40-45	50.00	4	200	5.32	80	426	0.80	129	103
45+	50.00	0	0	10.00	0	0	1.50	35	53
		6053	6717		5704	5398		361	213

Note: Daily equivalent damage units = 12,328 and annual DUs = 4,449,686.

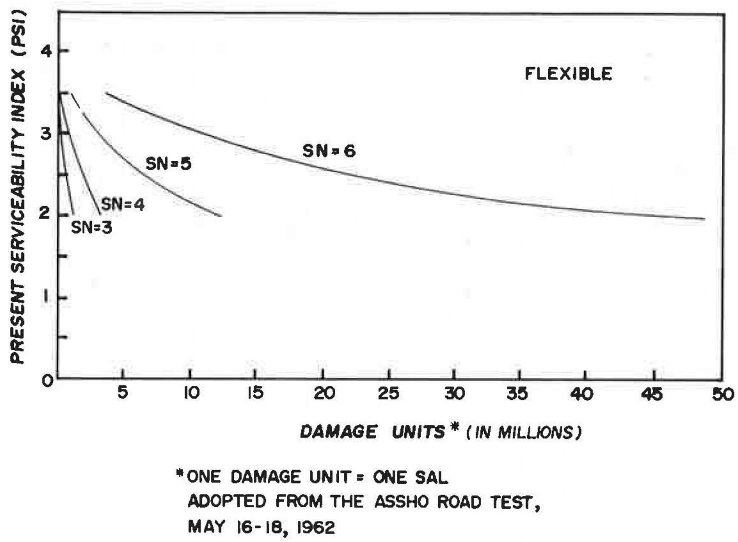

FIGURE 3 Present serviceability index versus damage units for flexible pavements.

(SN) in the Figure is an index that reflects the composition of the layered pavement structure:

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

where

D_1 = depth of pavement surface,
D_2 = depth of base course, and
D_3 = depth of subbase course.

Most common values for a_1, a_2, and a_3 are 0.44, 0.14, and 0.11, respectively. For the purpose of this analysis a structural number SN = 6 has been assumed. This is characteristic of a high-standard pavement structure capable of accepting significant load applications.

The present serviceability index (PSI) in Figure 3 is a rating, established by AASHO, that reflects the ability of the pavement to serve specific traffic requirements. When PSI drops below a critical value (e.g., PSI = 2.0), the pavement requires major rehabilitation of the entire layered structure so as to restore serviceability to its original level. This differs from routine maintenance and may be carried out before the PSI reaches the critical value for rehabilitation. In general, routine maintenance represents a minor component of rehabilitation expenditures and may be ignored for the purpose of this analysis (6).

The service life of the pavement, or the period between rehabilitation, can be determined for 1967 using the annual damage units estimated in Table 2 in conjunction with the AASHO serviceability relationship in Figure 3. Assuming a base year PSI value of 3.5 and a critical PSI value of 2.0, a total of 45 x 10^6 DUs can be tolerated between rehabilitation programs for an SN value of 6. This suggests that 10 years can be allowed between rehabilitation expenditures on the basis of the 1967 sample truck loadings.

The 1981 truck load profile was obtained for a sample of vehicles that were monitored at the MTC weigh-in-motion scale located on the eastbound approach of the 401 expressway near Whitby. These trucks were weighed between July 21 and August 3, 1981.

The axle load distribution for the 1981 truck sample is summarized in Table 3. The total weight carried within each weight interval and the number

TABLE 3 Truck Axle Weight Distribution, 1981

	Single Axles (62.6%)			Tandem Axles (36.9%)			Tridem Axles (0.5%)		
Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)	Percentage Axles	No. Axles	Total Weight (kips)
0-5	17.8	10627	26567	-	-	-	-	-	-
5-10	33.4	6647	49850	10.6	1243	9326	7.0	11	83
10-15	34.0	4060	50745	11.5	809	10117	7.0	7	83
15-20	7.5	640	11194	11.6	583	10205	5.0	3	60
20-25	5.0	332	7463	11.0	430	9677	1.0	1	12
25-30	2.3	125	3433	10.4	333	9150	1.0	1	12
30-35	-	-	-	16.6	449	14604	3.7	1	44
35-40	-	-	-	11.3	265	9941	4.0	1	48
40-45	-	-	-	8.6	178	7566	5.0	1	60
45-50	-	-	-	6.5	120	5719	18.6	5	222
50-55	-	-	-	1.4	23	1231	41.4	9	494
55-60	-	-	-	0.5	8	440	5.0	1	60
60+	-	-	-	-	-	-	1.3	0	15
	100.0	22431	149252	100.0	4441	87976	100.0	41	1193

Note: Daily number axles = 26,913; daily gross vehicle weight (adj.) = 238,420 kips (payload plus vehicles); vehicle weight (empty) = 38,420 kips; daily payload (constant) = 205,208 kips; and annual payload = 72,000,000 kips.

of axles in different combinations that carry this weight were modified to reflect the 1967 payload. The basic premise of this analysis is that the distribution of axle loads over the 1967-1981 period will adjust to new axle load limits. To ensure that axle load adjustments are not primarily a result of increased or reduced shipment levels over this period, the base year (1967) payload is applied to both 1967 and 1981 movements. In Ontario axle load limits were increased from 18 kips to 20 kips in 1968. The 1981 horizon year provides sufficient time for long-term changes to occur in response to the less restrictive load guidelines. A significant component of the change in the axle load distribution during the 13-year period, 1968-1981, may be technological in nature, reflecting changes in truck fleet composition. These changes require an extended period of time to occur. A horizon year that followed too soon after the axle load limit is adjusted would fail to capture these long-term effects. Because both the time of year and the general location of the two truck load samples for 1967 and 1981 are similar, changes in axle load distribution during the two time periods must occur in response to changes in the axle load limit. This is especially true given the adjustment for a constant payload during the 1967-1981 period.

The 1981 truck sample is subject to a single axle load limit of 20 kips. Although the payload has been assumed constant, the distribution of axle loads is expected to vary in response to less restrictive maximum allowable loadings. The empty weight component in Table 3 reflects the observed empty-to-gross vehicle weight ratio from the weigh-in-motion sample and an assumed constant daily payload of 205,208 kips.

The axle load distribution for 1981 from Table 3 suggests four trends for the period 1967-1981:

1. There is an increase in the proportion of single axles during this period. Single axles comprise 50.0 and 62.6 percent of the total axle passes in 1967 and 1981, respectively.
2. There is an increase in the proportion of heavy loadings that are allocated to tandem and tri-axle combinations, where the load transfer to the pavement is less pronounced. In general, despite a more generous load allowance, vehicle capacity in 1981 is being used more efficiently in relation to pavement deterioration.
3. Despite a constant assumed payload, the daily gross vehicle weight in 1967 is more than in 1981. In the latter year the empty vehicle component is a lesser proportion of the gross vehicle weight, which suggests a more efficient use of available truck fleet capacity. Clearly this is due to technological improvements rather than to the increase of the axle load limit.
4. The higher axle load limit in 1981 has not eliminated the incidence of overload axles in the sample. In general, overload single axles are reduced from the 30 percent level in 1967 to approximately 15 percent of the sample in 1981, although overloaded tandem axles in 1981 are similar in proportion to 1967 values at approximately 28 percent of the sample. The overload tri-axle proportion in 1981 has increased significantly from 1967, to approximately 60 percent of the sample from 45 percent in the earlier year.

It would be inappropriate to suggest from these results that reduced damage to pavement can follow an increase in allowable axle loads. Clearly technological developments during an extended 14-year period play a significant role in this observation. Nevertheless, axle load limits are not the central issue here. The truck fleet changeover between 1967 and 1981, which has allowed more efficient use of available vehicle capacity, has also produced reduced pavement deterioration for the same payload. In the long run, it can be argued that a truck fleet changeover to more efficient loading profiles should be a fundamental premise in any long-term guidelines that restrict axle loads.

Table 4 gives a summary of the damage unit results for 1981 based on the load factors designated in Figure 2. Interestingly, the reduction in single axle violators and the more efficient allocation of loads to tandem and tri-axle combinations have caused a reduction in damage units, despite an increase in axle load limit. In 1981 approximately 3.4 x 10^6 DUs per year were estimated. This suggests an increased rehabilitation cycle of 13 years. Despite an increase in the maximum allowable single axle load limits in the latter year, reduced pavement rehabilitation costs continue to be realized during the 1967-1981 period. This cost reduction is due essentially to truck fleet changeover and more efficient use of available vehicle capacity. Whether this development can be expected to take place indefinitely, or even in the short-run situation, is a concern that will be addressed later in this paper.

TABLE 4 Damage Units for 1981 Truck Axle Loads

	Single Axles			Tandem Axles			Tri-Axles		
Weight	Load Factor	No. Axles	Equivalent DU (18 kips)	Load Factor	No. Axles	Equivalent DU (32 kips)	Load Factor	No. Axles	Equivalent DU (44 kips)
0-5	0.05	10627	531	0.05	-	-	0.05	-	-
5-10	0.10	6647	665	0.05	1243	62	0.05	11	1
10-15	0.15	4060	609	0.10	809	81	0.05	7	0
15-20	1.00	640	640	0.15	583	87	0.05	3	0
20-25	3.05	332	1013	0.20	430	86	0.15	1	0
25-30	10.00	125	1250	0.40	430	133	0.20	1	0
30-35	25.00	-	-	1.00	333	449	0.30	1	1
35-40	40.00	-	-	2.80	449	742	0.50	1	1
40-45	50.00	-	-	5.32	265	947	0.80	1	1
45-50	50.00	-	-	10.00	178	1200	1.50	5	8
50-55	50.00	-	-	30.00	120	690	2.50	9	23
55-60	50.00	-	-	32.00	23	256	4.50	1	5
60+	50.00	-	-	50.00	8	-	15.00	0	0
		22431	4708		4441	4733		41	40

Note: Daily equivalent DU = 9,481 and annual damage = 3,413,160.

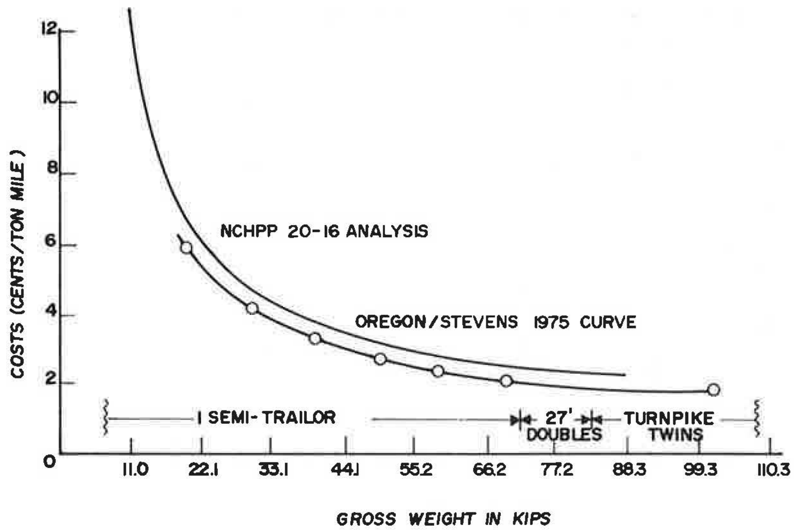

FIGURE 4 Costs per payload for fully loaded vehicles in 1974 U.S. dollars *(1)*.

INCIDENCE OF COST AND BENEFITS

For the purpose of benefit-cost analysis, the truck fleet in 1967 and 1981 is assumed to consist of three types of vehicles:

Type I	3-S2 and UD-5
Type II	3-S3 and UD-6
Type II	3-S2-3, UD-7, 3-S3-3, UD-8, and UD-9

Data on the distribution of gross vehicle weights for other truck types in 1967 were not available. In 1981 these categories represented 46.4 percent of all truck types monitored at the weigh scale or approximately 60 percent of the total equivalent 18-kip loadings.

Figure 4, taken from NCHRP Report 198 (1), shows the unit vehicle operating costs in cents per ton-mile against varying gross vehicle weights in kips. This relationship is consistent with different axle combinations and vehicle types. Figure 4 was applied to the axle load distribution for the 1967 and 1981 truck sample, for the three vehicle types noted, to give the unit vehicle operating costs summarized in Tables 5 and 6. The average unit vehicle operating costs for the 1967 and 1981 truck sample were remarkably similar in value, \$2.73 per ton-mile for 1967 and \$2.70 per ton-mile for 1981. Multiplying through by the annual gross vehicle weight in each year yields the total truck vehicle operating cost associated with transporting a constant payload of 72 x 10^6 kips per year under the two single axle load limits of 18 kips and 20 kips. Annual truck vehicle operating costs in 1967 and 1981 were estimated at \$1.103 x 10^6 and \$1.034 x 10^6 (1974 U.S. dollars), respectively.

In an earlier study on axle load limits in less developed countries, Saccomanno and Abdel Halim (7) concluded that truck vehicle operating costs are the dominant cost component associated with axle load limit legislation when noncommercial vehicle operating costs are ignored. For the situation in Ontario, to ignore the automobile component of the traffic and its associated operating costs would be unacceptable because reduced pavement serviceability has its major cost impact on noncommercial traffic. This is shown in Figure 5 for different operating speeds.

The accelerated deterioration of the pavement in 1967 caused by increased equivalent 18-kip axle load applications is reflected in higher automobile operating costs at various PSI levels. The rehabilitation cycle is assumed to represent a reduction in PSI level from 3.5 to 2.0. This takes place over a 10-year period ending in 1967 and a 13-year period ending in 1981. Assuming a linear trend, the PSI versus pavement life relationship and the associated unit vehicle operating costs are shown in Figure 6. Because these costs are on a per vehicle basis, the annual totals depend on observed automobile traffic volume. For 1967 and 1981 annual automobile vehicle operating costs were estimated for two levels of automobile AADT:

	AADT 14,000	AADT 95,000
1967	\$706,000	\$4,788,000
1981	\$202,000	\$1,368,000

All costs are in 1974 U.S. dollars.

Again, because DUs in 1981 were lower than in 1967, the vehicle operating costs for noncommercial traffic are also lower. The important aspect to note here is the relative magnitude of these values in relation to truck vehicle operating costs. On roads where automobile traffic is light, truck costs dominate. However, on high automobile volume roads, vehicle operating costs are considerably more pronounced for automobiles than for trucks, especially in 1967 when pavement deterioration was more accelerated.

TABLE 5 Vehicle Operating Cost by Gross Vehicle Weight and Truck Type (1974 U.S. dollars)

Gross Vehicle Weight (kips)	Unit Cost (c/T-M)	Type I Vehicles (%)	Type II Vehicles (%)	Type III Vehicles (%)
0-10	12.0	0.0	0.0	0.0
10-20	8.0	0.1	0.0	0.0
20-30	5.8	4.1	0.7	0.0
30-40	4.3	5.3	1.4	0.0
40-50	3.9	5.9	0.5	0.1
50-60	3.0	9.8	0.4	0.0
60-70	2.8	21.0	1.2	0.1
70-80	2.0	35.8	5.7	0.0
80-90	1.9	0.8	4.0	0.0
90-100	1.8	0.3	0.1	0.1
100+	1.8	0.1	0.0	2.5
		83.2	14.0	2.8

Note: Unit cost per variable: Type I = 2.32 c/T-M, Type II = 0.36, Type III = 0.05; total cost = 2.73 c/T-M; and total cost = \$3063.33 per day.

TABLE 6 Vehicle Operating Cost by Gross Vehicle Weight and Truck Type (1974 U.S. dollars)

Gross Vehicle Weight (kips)	Unit Cost $/T-Mi	Unit Cost $/Mi ÷2.2406	Type I Vehicles (% 3S2)	Type II Vehicles (% 3S3 UD6)	Type III Vehicles (% UD8 UD9)
0-10	12.0	0.60	0	0	0
10-20	8.0	1.20	0.1	0.0	0.0
20-30	5.8	1.45	5.4	0.7	0.6
30-40	4.3	1.51	11.0	2.8	3.2
40-50	3.9	1.76	13.4	1.9	2.9
50-60	3.0	1.65	21.4	2.7	0.9
60-70	2.8	1.82	11.4	2.8	0.6
70-80	2.0	1.50	12.4	3.5	1.0
80-90	1.9	1.62	10.8	5.4	2.4
90-100	1.8	1.71	10.7	12.0	3.9
100+	1.8	2.70	3.7	67.4	84.5
			100.0	100.0	100.0

Note: Unit cost per variable: Type I = 2.10 c/T-M, Type II = 0.45, Type III = 0.15; total cost = 2.70 c/T-M; and total cost = $2,873.04 per day.

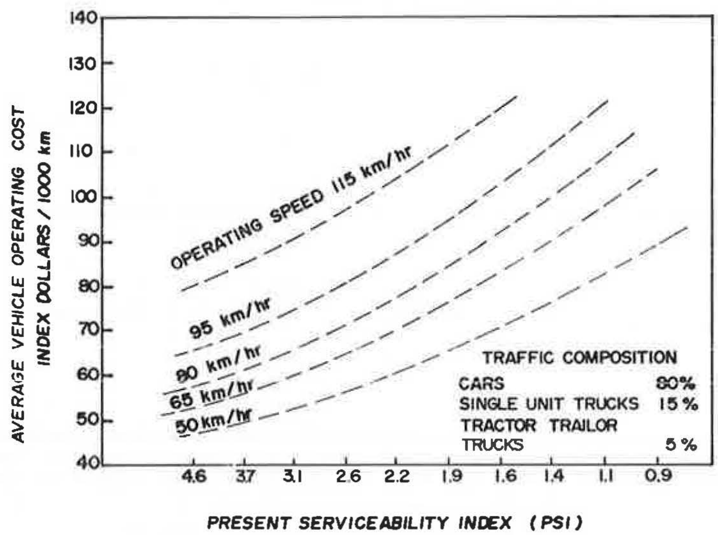

FIGURE 5 Vehicle operating cost index for rural, free-flowing conditions, after Haas and Hudson *(7)*.

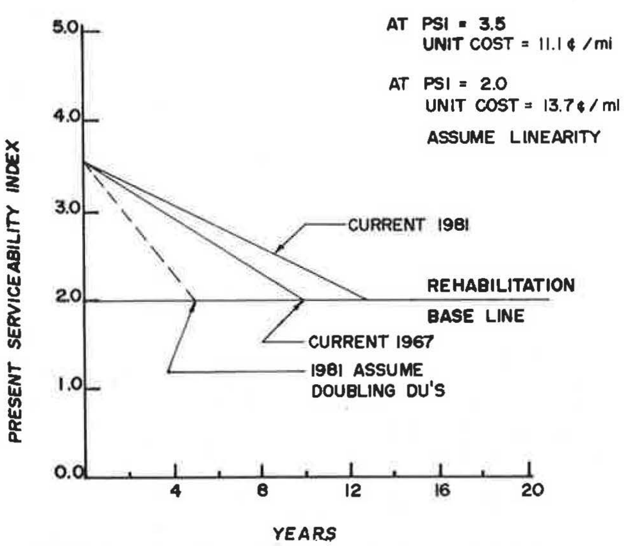

FIGURE 6 Automobile vehicle operating costs of various serviceability levels.

Annual pavement rehabilitation costs were estimated for 1967 and 1981 on the basis of a unit cost of $250,000 per lane-mile. For the 10-year rehabilitation cycle in 1967, the annual pavement deterioration cost was estimated at $14,000 per lane-mile. Clearly, pavement rehabilitation costs are a small component of truck and automobile operating costs and can be ignored in a benefit-cost analysis. From the point of view of economic viability, pavement deterioration costs are simply not an issue in setting effective axle load limits.

The results of these cost estimates are summarized in Table 7. As expected, depending on the assumed automobile volume, annual costs in 1981 are from $578,000 to $3,494,000 lower than in 1967. The shift in axle load limit from 18 to 20 kips per axle is clearly a cost-effective strategy. Because pavement deterioration is reduced in the latter year, everyone benefits from the higher limit.

As noted previously, it is unlikely that the truck fleet changeover that took place between 1967 and 1981 would also occur in the period immediately following a change in axle load limit. In the absence of technological advances, which give rise to a more

TABLE 7 Annual Costs and Benefits of Changing Axle Limit (thousands of 1974 U.S. dollars)

	At $250,000 per Lane-Mile	Automobiles AADT 14,000	Automobiles AADT 95,000	Trucks	Annual Net Benefit
1967	14	706	4,788	1,103	
1981	9	202	1,368	1,034	
Difference	5	504	3,420	69	578 → 3,494
1967	14	706	4,788	1,103	
1981[a]	39	806	5,472	1,034	
Difference	-25	-100	-684	69	56 → 640

Note: Automobile vehicle operating costs tend to dominate cash flow when AADT is high.
[a]Assume doubling of damage units from 1967.

efficient use of vehicle capacity and reduced pavement damage, loss in pavement serviceability would obviously become more accelerated with a higher axle load limit. Table 7 gives a summary of the various annual cost components that would have occurred in 1981 if equivalent damage units had been doubled over their 1967 values. This is reflected in a rehabilitation cycle of 5 years (Figure 6). For this situation it would not be economically viable to increase axle load limits. Savings in truck operating costs are exceeded by losses from higher pavement rehabilitation costs and especially higher automobile operating costs. Depending on the number of automobiles in the traffic stream, this annual loss varies from $56,000 to $64,000 per lane-mile. Clearly the shift to higher axle loads under these circumstances would not be justified. Again the dominance of vehicle operating costs in this analysis is evident. This is especially true for automobile operating costs at high traffic volumes. Despite accelerated pavement deterioration under a 5-year rehabilitation cycle, annual rehabilitation costs remain a small component of the total costs and benefits to vehicle operators.

CONCLUSIONS

Several issues should influence the direction of future policies on axle load limits in Ontario:

1. Long-term changes in truck fleet composition to more efficient axle load distributions may produce conditions under which higher allowable axle loads are economically justified. This situation may not be realized in the short run. Thus it is important that axle load limits be continually monitored to reflect changing traffic conditions over time.
2. The relationship between axle load, tire pressure, contact stresses, and pavement deterioration has to be considered in more detail. This relationship would determine the actual causes of the observed damage to roads.
3. The availability of funds for extensive maintenance and rehabilitation programs has mitigated against the adoption of higher axle load limits, despite some obvious economic benefits of the strategy. This is clearly a cash flow problem that is likely to become more of a central concern as governments are subjected to more severe financial restrictions.

From the perspective of economic viability, the proportion of noncommercial traffic in joint use of the road system acts to curtail recommended increases in axle load limits. Where noncommercial traffic is appreciable, net increases in vehicle operating costs from reduced pavement serviceability offset benefits to the trucking industry from higher allowable axle loads. Again this appears to be true only in the short, run, where changes in truck fleet composition are not likely to be a factor.

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