SOME EVIDENCE ON THE TRADE-OFFS BETWEEN TRUCK OPERATING AND PAVEMENT DAMAGE COSTS

B.G. Hutchinson
and
J.J.L. Mallett

Department of Civil Engineering
University of Waterloo
Waterloo, Ontario
Canada

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INTRODUCTION

The principal stimulus to changes in truck weight and dimension regulations is the reduction in unit line haul operating costs achieved with higher gross vehicle masses (GVM's). Radbone, Phang and Dorton (1986) presented evidence at the first symposium on heavy vehicle weights and dimensions which suggested that line haul operating costs reached a minimum under Ontario operating conditions at GVM's of about 50 tonnes.

Studies of the global benefits and costs that are likely to flow from different sets of weight and dimension regulations have been conducted in a number of countries. Most of these studies have used a macroscopic approach in which the global benefits and costs likely to flow from particular sets of weight and dimension regulations have been estimated. These studies have not focussed specifically on the economic efficiencies of individual truck types that might be used to transport different GVM magnitudes.

This paper introduces some evidence on the trade-offs between decreasing unit line haul operating costs achieved through higher GVM's and the increased pavement damage costs created by these heavier loads. The evidence is developed for a number of truck types which are used to haul three "weigh-out" cargo types in Ontario. The analyses on which this paper is based have been conducted at the micro-scale, where the incremental savings in unit operating costs achieved through higher GVM's are compared with the additional pavement damage costs.

TRUCK TYPES ANALYZED

Three "weigh-out" cargoes have been used for the analyses reported in this paper and these are petroleum products, milk and bulk animal feed. These cargo types were selected since a range of truck designs are used to transport these commodities in Ontario.

Petroleum Tankers

Figure 1 shows the four tankers used to haul petroleum products and these range from a 20,500 litre capacity straight truck (GVM = 26.3 t) to a 59,000 litre capacity B-train double (GVM = 63.5 t). The B-train exploits fully the current Ontario weight and dimension regulations in that it operates at the maximum GVM of 63.5 tonnes and has an axle load distribution that satisifies the Ontario Bridge Formula.

Milk Haulers

Figure 2 shows the milk haulers analyzed and these range from a 20,500 litre capacity straight truck to a 41,400 litre capacity A-train tanker combination. These trucks are used by Inter-County Milk Transport based in Arthur, Ontario and their properties have been described by Nix, Clayton, Bisson and Sparks (1986) who have also discussed the impacts of the operating requirements of this company on their choice of truck types. Nix, Clayton, Bisson and Sparks have pointed out that while these configurations may not minimize line haul highway operating costs, they offer the mobility required on farms when milk is loaded.

GVM = 26.3 t
Tare = 10.38 t
250 HP Caterpillar
13-Speed

GVM = 52.4 t
Tare = 17.06 t
400 HP Caterpillar
13-Speed

GVM = 60.1 t
Tare = 18.6 t
400 HP Caterpillar
13-Speed

GVM = 63.5 t
Tare = 20.61 t
400 HP Caterpillar
15-Speed

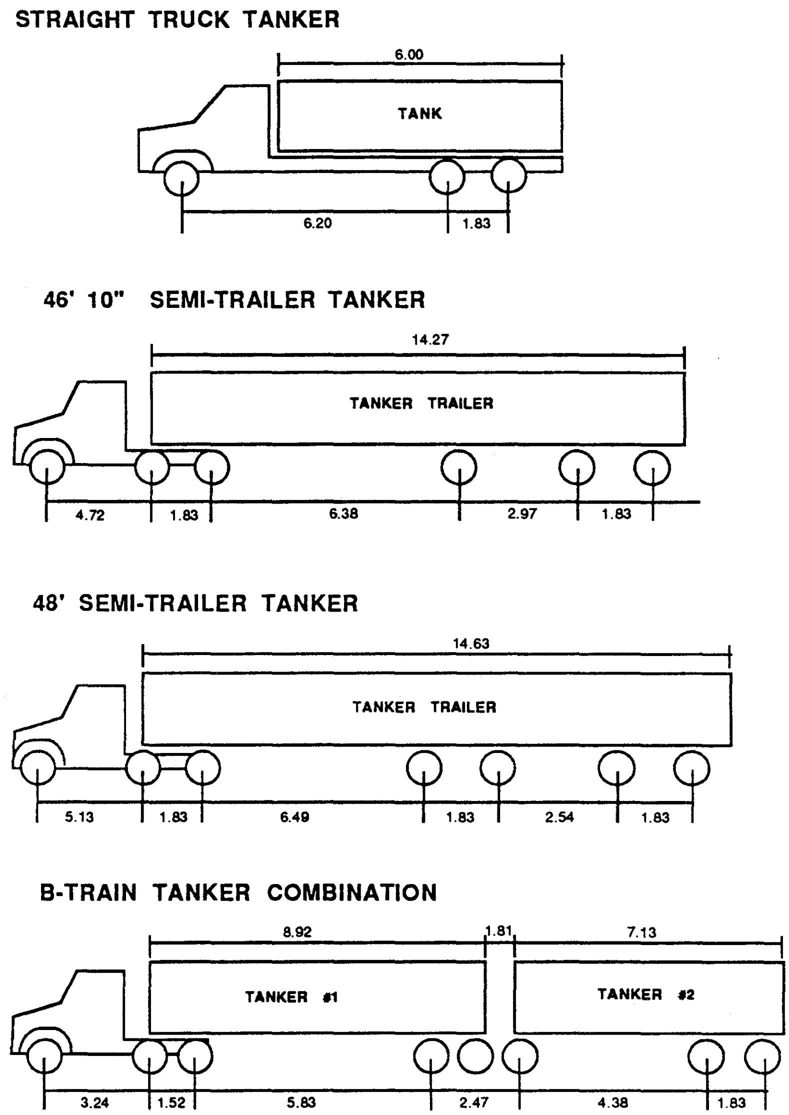
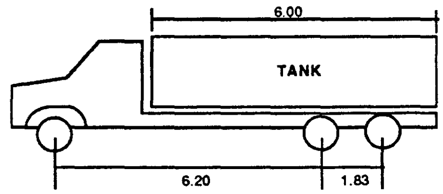


Figure 1. Petroleum Tankers

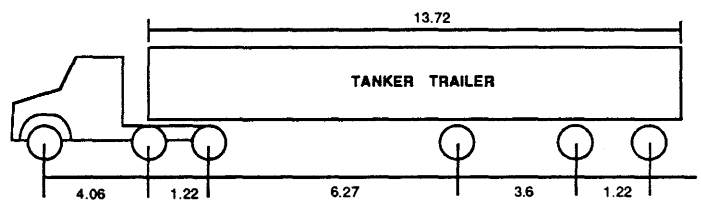
STRAIGHT TRUCK TANKER

GVM = 26.3 t
Tare = 10.38 t
250 HP Caterpillar
13-Speed



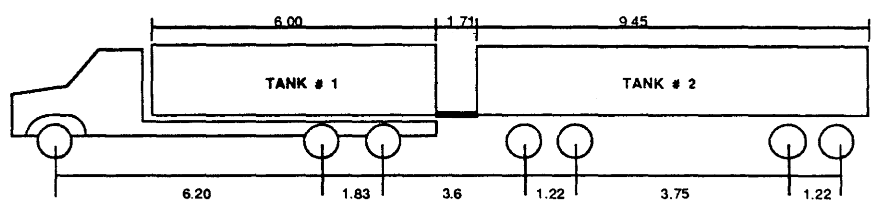
45' SEMI-TRAILER TANKER

GVM = 51.9 t
Tare = 18.71 t
400 HP Caterpillar
13-Speed



TRUCK PLUS TRAILER TANKER

GVM = 54.1 t
Tare = 16.64 t
400 HP Caterpillar
13-Speed



A-TRAIN TANKER COMBINATION

GVM = 63.4 t
Tare = 21.30 t
400 HP Caterpillar
13-Speed

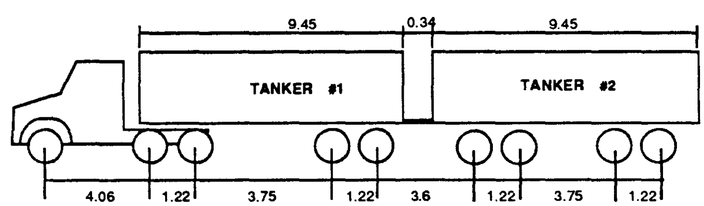


Figure 2. Bulk Milk Tankers

Bulk Feed Carriers

Figure 3 illustrates the set of bulk feed carrier vehicles analyzed, where these are representative of the vehicles used in rural farming areas in Southwestern Ontario. The trucks deliver animal feed prepared at central plants to a sequence of farms along their routes. A typical route covers 270-300 km. The vehicles illustrated in Figure 3 are used mainly because of the operating flexibility on farms. These vehicles are equipped with more axles than required by current highway regulations in order to reduce axle loads during off-higway operations. Two of the trucks have belly-axles which may be lifted during tight turns in farmyards.

Power Train Characteristics

Each truck was equipped with engine and transmission characteristics appropriate to the cargo density and truck type. In most cases these were the engine and transmission characteristics used by the operators. For some trucks the power train characteristics were based on the recommendations of local truck dealers. The engine and truck characteristics used for each truck are noted on Figures 1, 2 and 3. Hutchinson and Mallett (1989) describe these power train characteristics in more detail.

HYPOTHETICAL HAUL ROUTES

Figure 4 illustrates the hypothetical haul route used for each cargo type and truck type. Each truck was run over this route once per day and the unit line haul costs calculated for this operating frequency. While it is recognized that some of the smaller truck types might not be used for trips of this length it was decided to keep the haul route constant across commodity and truck types in order to ensure that the fixed costs were spread over the same annual distances and did not distort the estimated line haul costs.

CALCULATION OF UNIT OPERATING COST CHARACTERISTICS

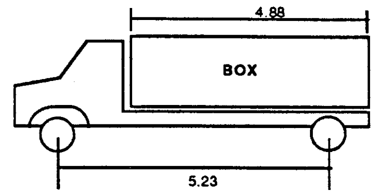
Figure 5 illustrates the sequence of steps used to calculate the line haul operating costs and this procedure has been programmed on a spread-sheet. Hutchinson and Mallett (1989) describe the technical basis of these calculations and list the unit costs used in the calculations. An hourly wage rate plus benefits of $15.63, a fuel cost of $0.43 per litre and an interest rate of 8 percent have been used in the calculations. It has been noted above that each vehicle has been assumed to make one trip per day.

PAVEMENT DAMAGE CHARACTERISTICS

The spreadsheet mentioned above also calculates the distribution of axle loads for each vehicle and load condition and estimates the relative pavement damage of each vehicle using the load equivalencies advanced by Rilett and Hutchinson (1988). The relative pavement damage of each truck is expressed as a number of ESAL's (equivalent single axle load) per truck pass, where the ESAL rating of a particular truck is the number of passes of a single axle load of 80 kN that would be required to create the same amount of pavement damage as one pass of a truck.

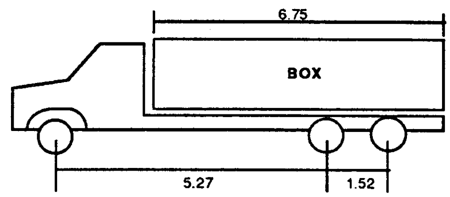
SINGLE AXLE

GVM = 15.42 t
Tare = 7.28 t
225 HP Caterpillar
5-Speed



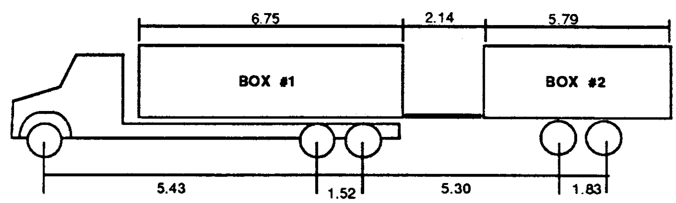
TANDEM AXLE

GVM = 24.37 t
Tare = 10.08 t
225 HP Caterpillar
15-Speed



TANDEM/PUP
TRUCK + TRAILER COMBINATION

GVM = 42.22 t
Tare = 10.02 t + 4.54 t
350 HP Caterpillar
13-Speed



QUAD/PUP
TRUCK + TRAILER COMBINATION

GVM = 52.94 t
Tare = 11.57 t + 4.54 t
400 HP Caterpillar
10-Speed

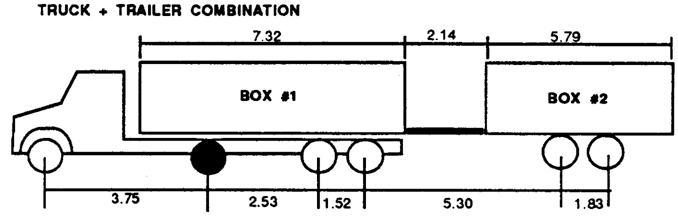


Figure 3. Bulk Feed Carriers

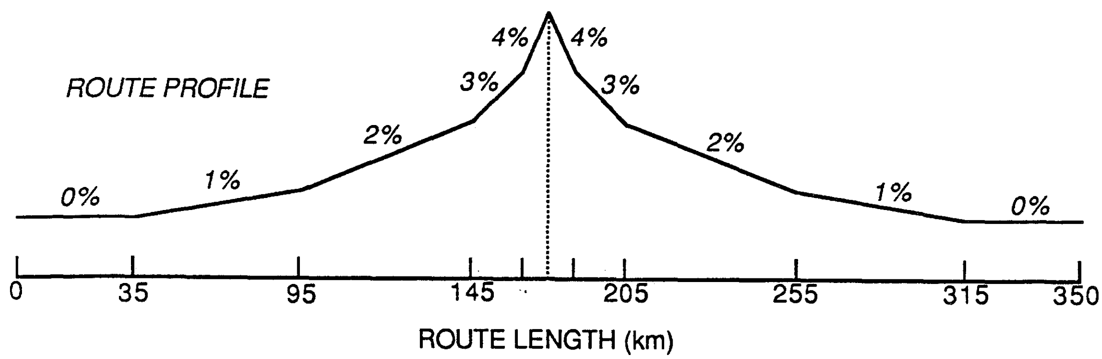


Figure 4. Hypothetical Haul Route

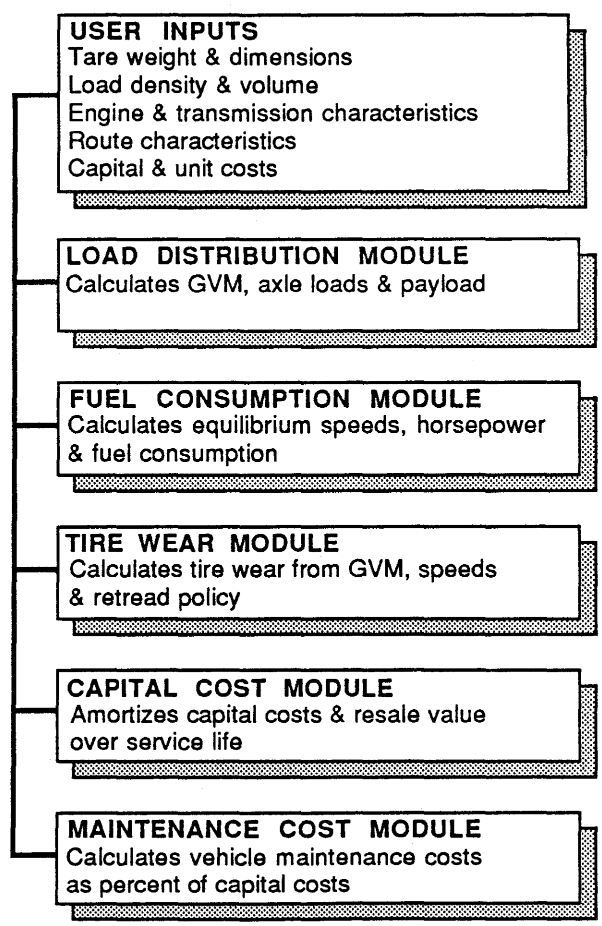


Figure 5. Line Haul Operating Cost Calculation Procedure

PETROLEUM TANKERS

Figure 6 shows the line haul operating cost and pavement damage characteristics estimated for each of the four petroleum tankers as a function of the payload transported by each tanker. The diagram shows that the line haul operating costs per tonne of payload decrease systematically with increasing payload with a slight increase in line haul costs for the B-train double which has the highest payload. This higher unit line haul cost for the B-train versus the quad-axle tanker is due primarily to its higher purchase cost ($215,000 vs $182,000) as well as its higher tare (20.6 tonnes vs 18.6 tonnes). This higher unit line haul cost occurs in spite of the 1,000 litre higher capacity of the B-train double. Hutchinson and Mallett (1989) have provided some evidence from the petroleum transportation industry to show that the estimated line haul costs of the larger truck types are close to those observed.

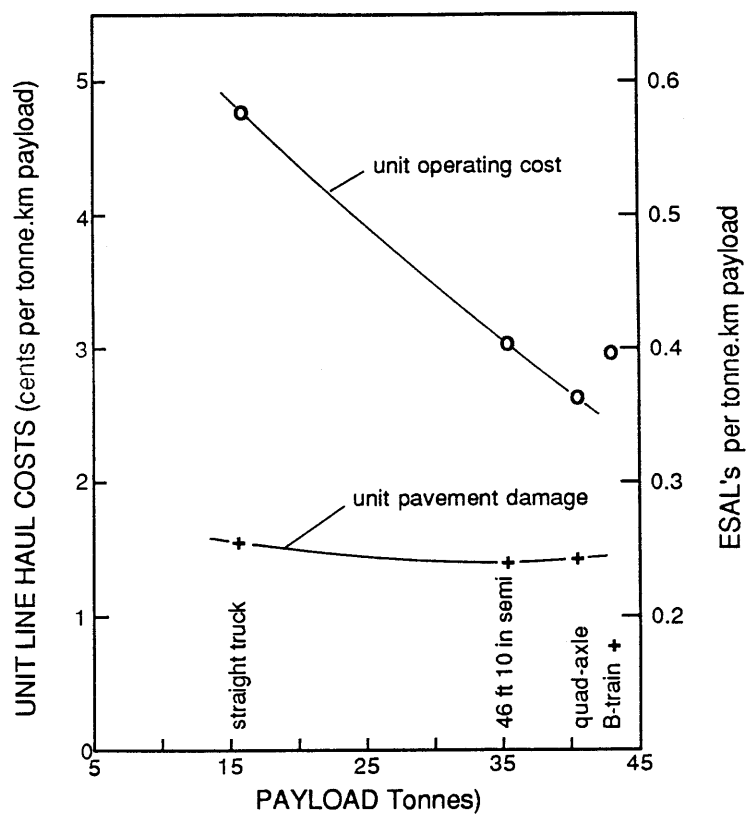


Figure 6. Unit Line Haul Cost and Pavement Damage Characteristics of Petroleum Tankers

Figure 6 shows that the unit pavement damage (ESAL's per tonne-km payload) decreases to about 0.24 ESAL's per tonne-km and then increases sharply for the quad-axle tanker. The B-train double creates much lower pavement damage than the quad-axle tanker. It should also be noted that the relative pavement damage of the B-train is also lower that that of the 46 ft 10in semi-trailer which has a GVM of 10 tonnes less than the B-train. This is not suprising since the semi-trailer units are equipped with fewer axles than the tanks of the B-train.

The two sets of information presented in Figure 6 allow the trade-off between operating cost and pavement damage savings to be examined. The operating cost and pavement damage characteristics of the B-train and quad-axle tankers are summarized below :

	line haul cents/t.km	pavement ESAL's/t.km
B-train	2.95	0.184
quad-axle	2.61	0.242

This means that the unit operating cost saving per ESAL is (2.95-2.61)/(0.242-0.184) = 5.9 cents/ESAL. If this is less than the life cycle pavement costs per ESAL then the quad-axle tanker would be more economically efficient than the B-train in terms of both public and private costs.

PAVEMENT DAMAGE COSTS

The allocation of life cycle pavement costs to different vehicle types may be achieved by separating these costs into common costs (pavement costs that are due to environmental degradation) and joint costs (costs that are due to load-associated effects). Common costs are allocated across the entire vehicle population while joint costs are allocated to individual vehicle types on the basis of a responsibility measure, usually ESAL's per vehicle.

Rilett, Hutchinson and Haas (1989) used the Ontario flexible pavement deterioration model to estimate the joint costs per ESAL for a range of truck volumes and pavement design strategies. An analysis period of 20 years was used along with initial year ESAL loadings which ranged from 250,000 per year to 2,000,000 ESAL's per year. The annual growth in ESAL's was assumed to be 2 percent.

Table 1 shows that the average joint costs per ESAL-km decrease with increasing ESAL loadings and this reflects the economies of scale that occur with highway pavements (the rate of increase in pavement thickness decreases with increasing ESAL loadings). Pavement life cycle costs increase with increasing traffic loads but these costs are spread over more units producing a decrease in the average costs.

Table 1. Average Joint Costs per ESAL-km

Design Lane ESAL's in Base Year	cents/ ESAL.km
250,000	2.3
500,000	1.5
1,000,000	0.9
2,000,000	0.6

These low average joint costs reflect the mechanics of deterioration underlying the Ontario flexible pavement deterioration model. The share of pavement costs allocated to environmental degradation in the analyses reported by Rilett, Hutchinson and Haas (1989) varied from 60 to 85 percent. These high shares allocated to environmental degradation reflect the harsh winter conditions that exist in Ontario and the structure of the Ontario flexible pavement deterioration model.

This analysis of pavement costs indicates that the additional pavement costs created by the quad-axle tanker are less than the savings in unit transportation costs per ESAL even for highways with relatively low truck loadings. This conclusion does not mean that the costs recovered from quad-axle tankers, or even B-trains, are sufficient to cover the pavement damage created by these petroleum tankers.

The analysis also does not examine the safety characteristics of the two vehicle types. Sutherland and Pearson (1989) have reported that the 48 ft quad-axle tanker has static and dynamic rollover characteristics inferior to the B-train and lower than the reference standard set in the Canadian vehicle weights and dimension studies.

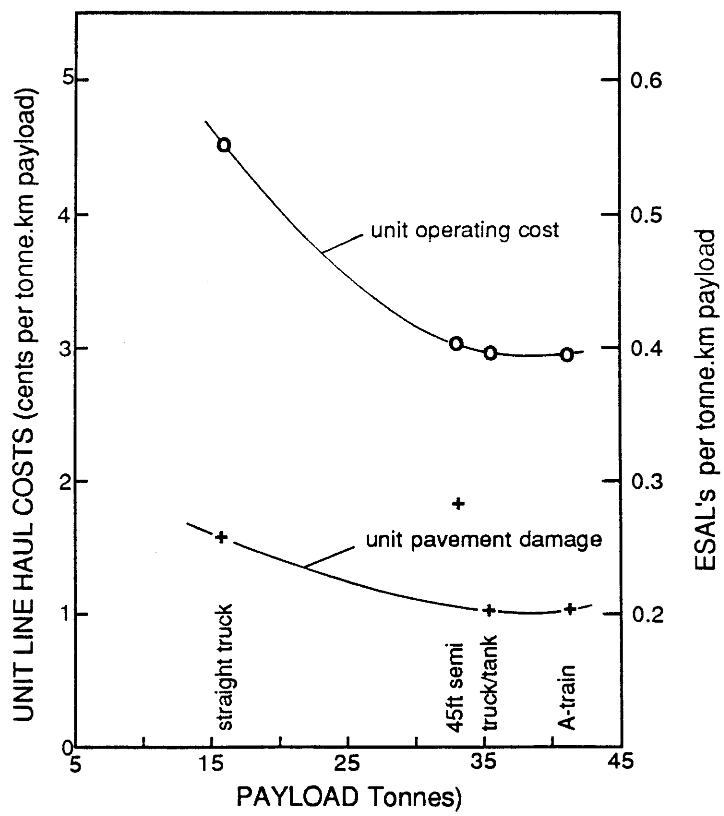


Figure 7. Unit Line Haul Cost and Pavement Damage Characteristics of Milk Haulers

MILK HAULERS

Figure 7 illustrates the unit operating and pavement damage characteristics of the milk haulers. The line haul cost function is similar to that calculated for the petroleum tankers. The lowest unit operating cost is achieved by the A-train, but this is only marginally lower than the truck plus tanker. The pavement damage function shows that there is little difference in the unit pavement damage characteristics of the two larger vehicles. These unit pavement damage magnitudes are lower than those for the petroleum tankers and this reflects the higher numbers of axles used on the milk tanker fleet to achieve the farmyard mobility mentioned previously. The information in the graph shows that the truck plus tanker and the A-train double have similar unit operating cost and pavement damage characteristics.

BULK ANIMAL FEED CARRIERS

Figure 8 illustrates the operating cost and pavement damage characteristics of the bulk feed carriers. The operating costs reach a minimum with the quad-axle truck plus pup trailer. The unit pavement damage function decreases to a minimum of about 0.23 ESAL's per tonne.km and increases marginally for the heaviest truck combination.

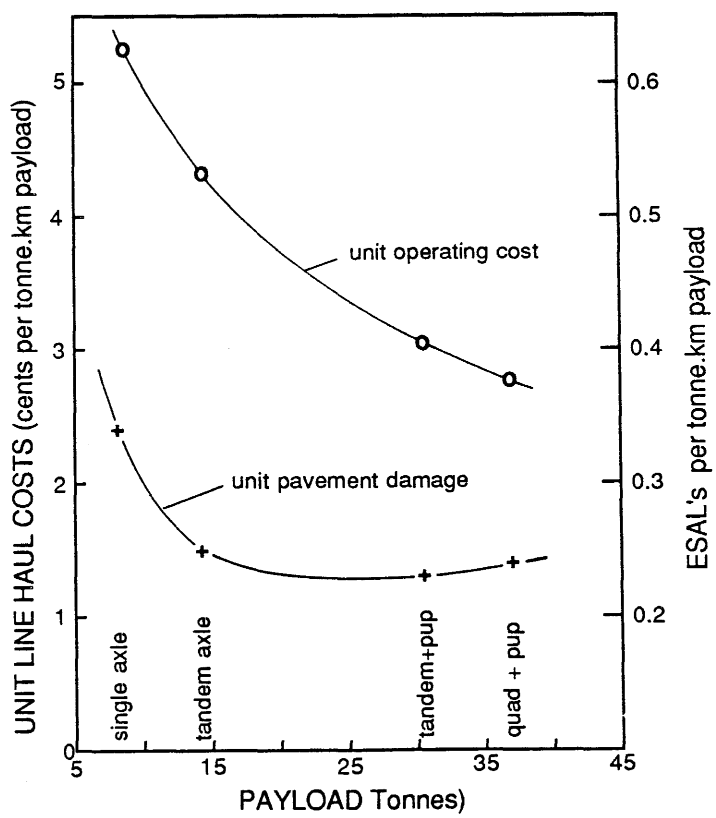


Figure 8. Unit Line Haul Costs and Pavement Damage Costs for Bulk Feed Carriers

The operating cost and pavement damage characteristics of three of the bulk feed carriers are summarized below:

	line haul cents/t.km	pavement ESALs/t.km
tandem axle truck	4.33	0.25
tandem + pup	3.02	0.23
quad-axle + pup	2.74	0.23

The additional load carried by the tandem + pup trailer versus the tandem axle truck results in a saving of about 65 cents/ESAL which means that tandem + pup configuration is economically efficient. The table also shows that the lower unit costs achieved by the more heavily loaded quad-axle + pup are achieved without any significant increase in the unit pavement damage costs, and this means that this vehicle type is economically efficient.

CONCLUDING REMARKS

This paper has summarized some analyses of the economic efficiencies of a variety of truck configuartions used to transport "weight-out" commodities in Ontario. A micro-approach has been used in which the savings in line-haul operating costs achieved by higher GVM's are compared with the additional pavement damage costs created by the higher GVM's.

The analyses showed that the unit line haul costs approached a minimum for payloads of 35-40 tonnes (GVM's of 54-60 tonnes). The increases in pavement damage costs created by the trucks designed for the transport of bulk feeds and bulk milk were less than the savings in line haul costs for most truck types. This is mainly because the vehicles are designed for off-highway use and have lower than legal axle loads. The increased operating costs created by these additional axles were very small.

The analyses of the petroleum tankers presented the classical trade-off problem faced by highway authorities. The unit line haul costs of the quad-axle semi-trailer tanker were estimated to be about 11 percent lower than for the B-train double. These lower costs are due to the lower tare of the quad-axle tanker (2 tonnes less than the B-train) and its $30,000 lower purchase cost. The use of four axles rather than the five used on the B-train tankers produces a sharp increase (32%) in the pavement damage created by the quad-axle tanker.

The evaluation presented in this paper suggested that the quad-axle tanker is more efficient because the reduction in line haul costs were estimated to be greater than the additional pavement damage costs. This conclusion is sensitive to the magnitude of the average joint pavement costs assigned to traffic. The Ontario flexible pavement deterioration model allocates a high share of pavement life cycle costs to environmental degradation, and therefore to common costs. This conclusion about the efficiency of the quad-axle tanker may not be reached with other pavement deterioration models where a greater share of pavement damage is assigned to traffic. Joint pavement costs greater than 6 cents per ESAL would make the quad-axle tanker economically inefficient.

It must be emphasized that this paper has focussed on the economic efficiencies of different truck configurations and has not addressed the adequacy of current road user charging schemes.

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WORKSHOP 2 – VEHICLE TECHNOLOGY

Chairman: P. Sweatman, Australian Road Research Board

Presentations

1. **Research and Development Opportunities for Advancing Highway Freight Transport Technologies**
   S. Vespa, Transportation Development Centre

2. **Self Steering Axle Design and Application Considerations**
   J.H.F. Woodrooffe, National Research Council

OPEN DISCUSSION