Truck and Highway Combinations for Increasing Trucking Productivity in Market Niches

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The focus of this work is at the system level instead of the component level of the autotruck highway system. New combinations of trucks, roads, and operations that could achieve sizeable productivity gains if introduced into the truck-highway system are explored. A simulation model to assess the benefits expected from new truck and road combinations is developed. Grain transportation in rural areas is chosen as a possible market niche. The results of the case-study analysis indicate that trucks of up to 200,000 lb gross vehicle weight operating on a network of low-maintenance roads present an opportunity for substantial productivity gains. The new combinations can offer services four to six times less costly than those of present day grain shipping. Institutional and operational changes necessary to the implementation of such truck-highway formats are discussed.

Trucking has become the principal mode of freight transportation as measured by expenditures, accounting for roughly 70 percent of the nation's freight bill (*1*). While truck transportation continues to grow in absolute terms (in terms of tonnage carried), by the early 1960s, trucks had captured about 90 percent of their present share of the freight transportation market. Market share subsequently has been relatively stable, fluctuating at around 25 percent for the ton-miles carried and between 35 and 39 percent for the total tonnage of freight carried.

Although there may be disagreement among researchers on measuring trucking productivity, indications are that productivity growth as traditionally measured is much slower today than it was between the 1930s and early 1970s. For example, the growth of output per employee dropped from 3.70 for the period 1948 to 1973 to −0.28 between 1973 and 1987 (*2*). However, the trucking organizations serving modern logistics systems have changed the characteristics of their services. These important changes are not reflected in traditional productivity measures.

One action to increase trucking productivity has been to allow larger and heavier vehicles to operate over certain highways. The effects of increases of truck size and weight limits have been unequal among those engaged in trucking, for truck operations take place in highly varied circumstances. Changes in weight and length limits are more important to some segments of the trucking industry than to others. Today, greater trailer lengths mainly benefit carriers and shippers of low-density cargoes, whereas carriers of high-density goods are constrained by weight limits. Furthermore, highway engineers are dissatisfied with current standards of truck size and weight limits because heavier traffic accounts for the larger fraction of road wear, increasing the pressure on an aging infrastructure.

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PERSPECTIVE

The damage caused by truck axles, requirements for pavement strength to handle weights, and road tax-cost relationships have undergone much study, mainly at the national aggregate and road test level. Part of this work has looked hard at larger and heavier trucks (*3*) and highway tax allocation (*4*). More recently, there has been interest in new truck designs (*5*). In nearly all cases, the present debates and investigations of heavier and larger trucks take as givens the previous evolution and current status of the truck-highway system (equipment, fixed facilities, taxation, institutions, etc.). Typically, most of these studies recommend further liberalization of truck size and weight limits (*4–10*). Recommendations are for small, marginal changes nationwide on specially designated networks.

The alternative is to seek changes, market niche by market niche. Put another way, the present thrust is for "one suit fits all" policies, and the alternative is to focus policies on specific markets and road infrastructure situations. For example, responding to the need to move heavy containers is being done to some extent in the vicinities of marine ports.

Why emphasize market niches? One reason is the cumulative experience of transportation and other technological systems as they traverse their life cycles. The trucking system, along with most other transportation activities, may be regarded as a mature activity, having grown along an S-curve and saturated its markets, hardening its predominant technological, institutional, and service formats along the way (*11*). In this mature stage, firms compete and seek productivity improvements by specializing products or services to market niches (*12,13*). There is much evidence of such behavior in the trucking industry (e.g., the growth of firms serving just-in-time and container collector and distributor markets). A second reason for considering market niches is that services in market niches may discover pathways for the evolution of important new services, pathways replicating the ways changes have occurred in the past (*14–16*).

The perspective of this work has now been stated. Concern is with advances in market niches that may open new development pathways. Designs are to have a system scope and use the building blocks at hand.

IDENTIFICATION OF TECHNOLOGICAL FORMATS AND POTENTIAL MARKET NICHES

There appear to be no significant technological barriers to designing and operating specialized trucks considerably larger than those

permitted today on the Interstate system, as examples from logging areas and open pit mines indicate. There are also examples from other countries. In Canada, six provinces have a limit of 50,000 kg (110,000 lb), four have a limit of 56,750 kg (125,000 lb) or more, with a maximum of 63,500 kg (140,000 lb) in Ontario. Equally relevant to the discussion would be the Australian road-train experience, in which trucks of up to 136,000 kg (300,000 lb) gross vehicle weight (GVW) are allowed to operate on designated routes. Therefore, using current truck technology as a first building block of a new system would be a natural beginning. Other in-place building blocks include roads and operation protocols.

The technological format to be tested must be at first an effective substitute for an existing service, while at the same time presenting a potential for improved service, lowered costs, and productivity increases. That is, introduction should be incremental, but the new format should have the potential to provide great improvement over the previous system configuration. Short-term gains must be substantial, because only such payoffs would stimulate others to explore further or emulate the new technological format in other locations.

What about market niches? Potential niches include

- Areas that are currently experiencing problems either as a result of heavy truck traffic or inadequate service,
- Areas in which the changes in socioeconomic conditions have in turn generated changes in the demand for freight services, and
- Gaps in the existing system or some transportation functions that are not well performed.

Overall, the niche should allow degrees of freedom. Even if a trial design is quite successful, for example on cost-saving grounds, there would likely be a need for continued design changes. Further, however the design emerges, room is needed for continued growth and development. The notion is advanced that a successful design will open a pathway and continued progress will be achieved by learning, feedback, modifications, and so on.

ANALYSIS APPROACH

Given the scope of the present study, the models available in the literature that simulate vehicle operations, pavement, and bridge impacts are quite satisfactory for measuring the cost impacts of a wide range of truck and highway configurations. Models adapted from the literature for this study use a combination of theoretical concepts and empirically derived relationships to evaluate the impact of the various vehicle configuration alternatives. (Note that "using what is available" is consistent with the notion of using available building blocks.)

The conceptual model begins with an exogenously specified set of service requirements (Figure 1). Based on the volume and density characteristics of the goods to be transported, the model begins by specifying a vehicle configuration (number of trailers and axles) and computing the trailer length, tare weight, effective payload, and GVW for the particular truck configuration. Once the vehicle's physical characteristics are determined, the model computes the vehicle operating costs required to ship the volume of freight. Next, the model computes fixed facility requirements, including pavement maintenance, and geometric and bridge costs. Vehicle and road costs are added to determine the total cost. The model then allows for feedback between vehicle configurations and fixed facility requirements to evaluate the performance of particular truck-road configurations. The simulation is carried out again with a new higher or lower GVW until a minimum total cost is reached for the particular truck configuration. Similarly, the simulation is run again for the particular truck configuration with a different road configuration (such as that with existing pavement, thicker pavement, or gravel roads). Once a particular truck and road configuration reaches its minimum total cost, it is compared with present-day truck costs to estimate potential savings.

Vehicle Operating Cost Model

The vehicle operating cost (VOC) model begins by determining the horsepower requirements for a given speed and GVW by using the Davis equation. Once the horsepower is determined to be within the range of currently manufactured engines, the model checks for trailer and overall truck length. The length of trailers needed to carry the specific GVW is a function of the truck combination tare weight, effective (useful) trailer volume, and the density of the freight to be transported. Next, the number of vehicle trips required, cycle times, and labor costs are determined. The model then computes the remaining components of operating

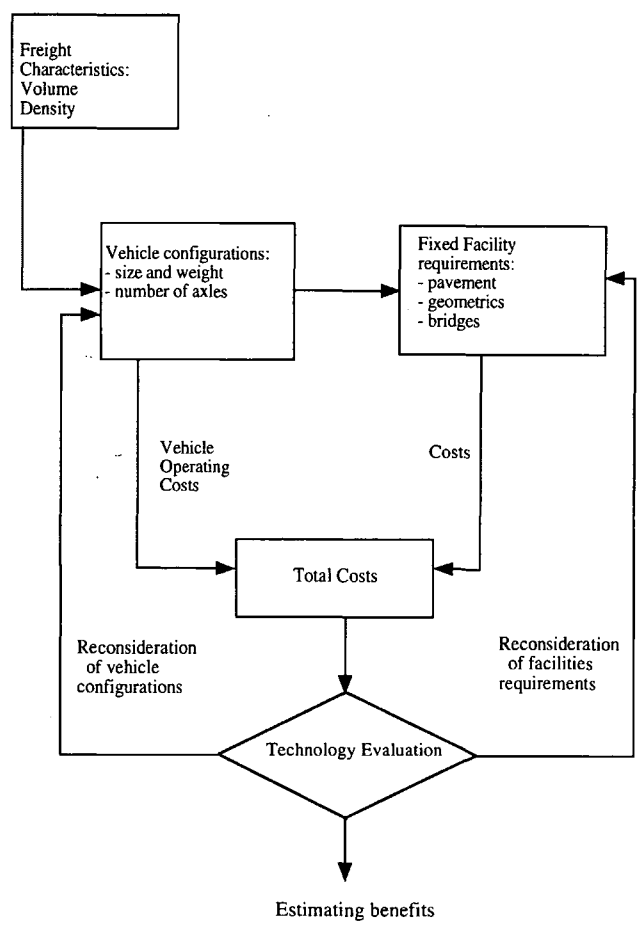


FIGURE 1 Conceptual model.

costs: tire, fuel, lubrication and maintenance, and depreciation. These cost relationships are taken from the Highway Research Board's (HRB's) *NCHRP Report 141* (*17*) and adjusted for inflation to reflect 1987 costs. However, extrapolating to heavy vehicles using the HRB estimating equation for maintenance costs resulted in overestimating heavy truck costs throughout the study. This, of course, means that the ratios of costs for heavy vehicles versus conventional vehicles are conservative throughout the study. Research is under way to improve the cost estimates.

Pavement Cost Model

Two approaches can be taken for estimating pavement costs resulting from changes in truck weights and configurations. One way would be to estimate the additional maintenance and associated rehabilitation costs resulting from the wear occasioned by heavier loads if no change in current maintenance practices is made. The amount of wear is measured by the reduction in the useful life of existing pavement. Alternatively, the additional pavement thickness required to maintain the level of service currently provided could be estimated.

Reduction in Pavement Life

One way to calculate the cost of the change in road maintenance costs resulting from the heavier traffic consists of the following steps:

1. Estimate the load distribution on each group of axles of the truck,
2. Obtain the total number of equivalent single axle loads (ESALs) that the pavement under consideration is designed to sustain during its lifetime. The total number of ESALs divided by the life of the road in years would be the total number of ESALs the pavement should sustain on a yearly basis,
3. Obtain the average maintenance costs for the road section allocated by the yearly expected traffic volume, and
4. Determine the additional variable maintenance cost required resulting from the heavier loads.

Given the paucity of available records on road maintenance, it might prove difficult to obtain accurate data required for Steps 2, 3, and 4 as described. As a result, some of these data would be somewhat speculative.

Increased Pavement Thickness

Alternatively, pavement life can be increased by adding a new pavement layer, and the new variable maintenance cost can then be computed. The American Association of State Highway and Transportation Officials' design procedure (*18*) is used to determine the required pavement thickness. The cost of the additional layer of pavement is then estimated based on the unit cost of paving material for the particular geographical area.

DATA SOURCES AND ASSUMPTIONS

Highway transportation in rural areas is currently experiencing a host of problems, including a deteriorating physical infrastructure and fiscal difficulties. In this context, the transportation of agricultural products over rural roads presents a possible market niche for a new truck-highway design, and grain hauling was selected as a case study.

The case study involves the comparison of the costs of hauling one year's corn production from an average-size farm in Hamilton County, Iowa, to the local country elevator. Hamilton County was chosen because of the availability of road condition and maintenance data.

The analysis assesses how six truck configurations compare with current practice in terms of total costs, operating costs, and road maintenance costs (Figure 2). Configurations consist of a pair of single trailers, a pair of double trailers, and a pair of triple trailers. The GVW for each truck configuration varies from 36 tonnes (80,000 lb) to 136 tonnes (300,000 lb), subject to the constraint of realistic tractor and trailer dimensions. Truck configurations with a payload requiring unrealistic trailer dimensions were automatically discarded. When smaller loads required shorter trailer lengths, a default minimum of 6 m (20 ft) was used when computing truck tare weight. Furthermore, the truck configurations investigated do not comply with the axle load limits mandated by Bridge Formula *B*, as the following list indicates:

- The distance from the farm to the local elevator is assumed to be 16 km (10 mi), which is consistent with the average distance reported by a number of studies (*19,20*).
- Backhauls from elevators to the farm are assumed to be empty.
- Information regarding the rates of loading and unloading grain at country elevators was obtained by calling elevator operators in Iowa, Illinois, and Minnesota. Typical unloading rates vary with trailer size and are assumed to be 10 to 15 min/trailer.
- Information on grain-hauling truck configurations and equipment (hopper dimensions, GVWs, tire sizes, expected lives, etc.) was obtained from a number of sources. Tractor and trailer tare

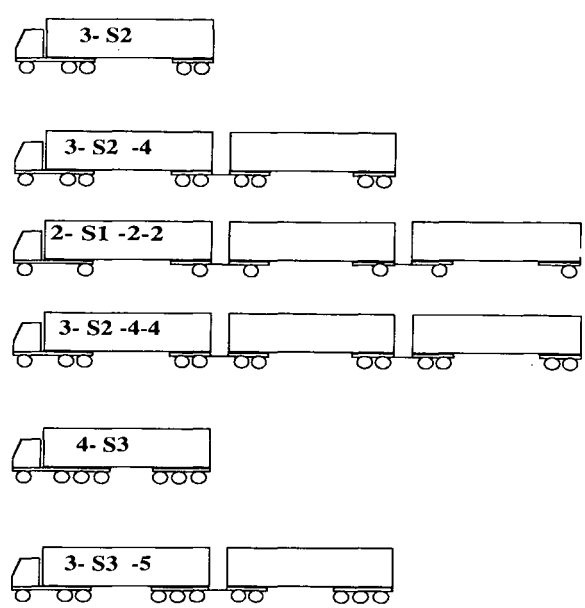


FIGURE 2 Six truck configurations.

weights and dimensions from Winfrey's study (*3*) were complemented by specification catalogs from grain truck manufacturers and the *Chilton Commercial Carrier Journal* (*21*). These values were extrapolated to obtain the tare weight and dimensions of larger and heavier truck configurations. As a further simplification to reduce the need for lane widening, trailer width and height were maintained at 2.45 m (8 ft) and 2.3 m (7.5 ft), respectively, throughout the study, whereas trailer length was allowed to vary as a function of GVW.

- The cost of labor for truck drivers was obtained from the Bureau of Labor Statistics and assumed to be $12/hr. This reflects direct cost.
- Diesel fuel cost was obtained from the United States' Statistical Abstract.
- Tire sizes, expected life in miles, and costs were obtained from tire manufacturers.
- Data on road conditions and maintenance costs were obtained from previous rural roads studies that surveyed highway officials and county engineers on the status of local road conditions, such as the study by Baumel (*22*) and the Iowa Quadrennial Need Study (*23*). As a further simplification, all roads on which the trucks will travel are assumed to have structural pavements.

EMPIRICAL ANALYSIS

Three different scenarios are analyzed. It is assumed that in each scenario only one type of truck configuration would carry the entire yearly farm production so as to provide a comparison of the relative efficiencies of each of the six vehicle classes.

The first scenario compares the total transportation costs for the six truck configurations under consideration with truck GVW allowed to increase to 136 tonnes (300,000 lb). The trucks haul the yearly production of corn from an average farm to the local elevator. Each truck configuration is compared with present-day typical trucks. The total transportation cost is the sum of the VOC and the road variable maintenance cost (RVMC). The VOC represents the cost of running the truck. The road maintenance cost consists of two parts. First, a fixed portion that is independent of the level of traffic and its composition. It includes the costs of signing, slope erosion, and snow removal. Second, the RVMC (the portion of the maintenance cost that varies directly with the number of axle loadings) provides for a comparison of the road wear and resulting pavement costs associated with each truck configuration.

The second scenario investigates the impact of letting the road deteriorate and compares the resulting increase in vehicle operating costs. The third scenario investigates the effect of an increase in pavement thickness on total transportation costs and determines the volume of grain movement that would be required to compensate for the cost of the added pavement. By varying the hauling distance, the last simulation looks at the effect of distance on the total cost per ton-mile for the six truck configurations.

Strategy 1: Higher Axle Loads Over Existing Roads

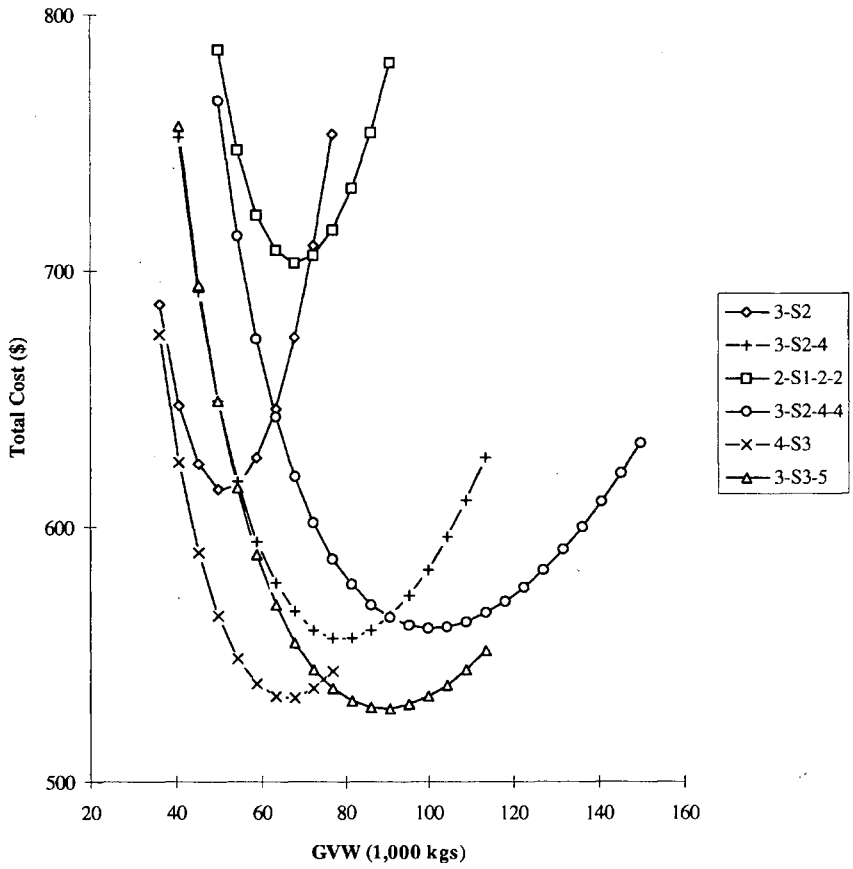
In this scenario, the total farm production of 636 tonnes (700 tons) of corn is shipped a distance of 16 km (10 mi) to the local elevator in each of the six truck configurations. The trucks' GVWs are increased from 36 to 136 tonnes (80,000 to 300,000 lb) and trucks travel over existing roads. The simulations estimate the vehicle operating costs and the road variable maintenance costs as defined earlier. Shown in Figure 3 is the combined effect of VOC and RVMC for each of the six truck configurations as the GVW for each truck configuration is increased in 4,540 kg (10,000 lb) steps. The total cost curve for each of the six truck configurations decreases over a range of weights before reaching a minimum and then increases. The minimum cost point varies considerably between trucks, the extremes being the 2-S1-2-2 with the highest total cost and the 3-S3-5 with the lowest. The number, as well as the type, of axles proves to be the more important factor as trucks with a larger number of axles (3-S2-4, 3-S2-4-4, and 3-S3-5) provide for the larger decreases in total costs. The type of axle group is equally important. Despite having a lower number of axles, the 11-axle 3-S3-5 truck provides for consistently lower total costs in comparison with the 13-axle 3-S2-4-4. This is mainly because the load in the former truck configuration is distributed over two tridem and two tandem axles that cause less damage to the road, whereas the latter has six tandem axles. Also contributing to the lower total cost is that for equal GVW, the double trailer has a lower unloading time than the triple trailer, thus reducing the cycle time and consequently the labor cost. Finally, for trucks with the larger number of axles, the 3-S2-4-4 and the 3-S3-5, the GVW beyond which costs cease to decrease is in the range of 91,000 to 99,000 kg (200,000 to 220,000 lb).

The total cost for the six different truck types under consideration was then compared with typical present-day grain-hauling trucks. At present, grain from farms to elevators is shipped by a myriad of different trucks, ranging from pickups to semi-trailer trucks, including farm tractors pulling one or two grain wagons. Chicoine and Walzer (*24*) report that straight trucks and farm tractors are the vehicles most frequently used by farmers in four Midwestern states, accounting for some 70 percent of all grain shipments, with tandem axle trucks accounting for about 10 percent. Therefore, it was decided to base the comparison of alternative truck configurations on three representative trucks: a 2-axle, 14,000-kg (30,000-lb) straight truck, a 17,000-kg (38,000-lb) farm tractor and a 350-bushel wagon combination, and a 24,500-kg (54,000-lb) commercial truck (one tandem and one drive axle). The total costs for these representative arrangements were computed using the same cost models as for the six truck configurations previously discussed.

The ratio of total costs of each of the six truck configurations to the costs of today's representative grain trucks was then calculated, showing that heavier truck combinations represent substantial savings over present-day grain trucks. At their highest points, the ratios vary between 4.7 and 3.5 in comparison with the farm-tractor and wagon, and between 3.8 and 2.9 when compared with a straight 14,000-kg (30,000-lb) grain truck. The ratios are 2.3 to 1.7 when the trucks are compared with a 24,500-kg (54,000-lb) tandem truck. The 3-S3-5 truck combination represents the highest overall savings of all trucks, whereas the 2-S1-2-2 triple-trailer achieves the lowest overall gains.

Strategy 2: Letting the Road Deteriorate

In this scheme, the analysis looks at the impact on the cost of hauling the grain from the farm to the country elevator when the road is allowed to deteriorate (i.e., eliminating variable maintenance cost). Of course, the fixed component of maintenance costs,



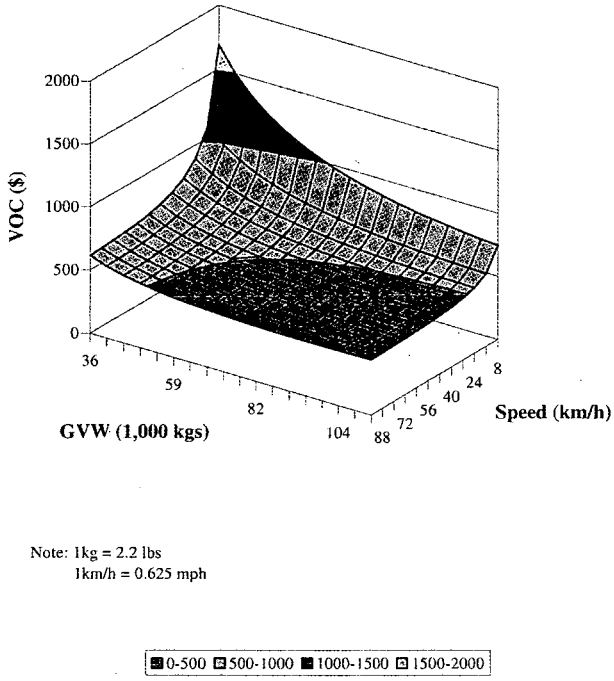
Note: 1kg = 2.2 lbs

FIGURE 3 Total cost per function of gross vehicle weight for six truck configurations.

which consists of snow removal, blading, and graveling, will be maintained. It is assumed that as the road condition deteriorates, vehicle speed will be reduced and tire life will be diminished, thus increasing truck operating cost. Because of the lack of data, other increase in truck maintenance costs caused by the deterioration of the road surface were ignored as a simplifying assumption. However, given that the HRB equations overestimate the truck maintenance costs, this simplification should not affect the overall results. Shown in Figure 4 is a typical curve depicting the changes in vehicle operating cost as truck speed increases from 8 to 96 km/h (5 to 60 mph) and GVW increases from 36,000 to 114,000 kg (80,000 to 250,000 lb). The vehicle operating cost curves for all six truck configurations display similar patterns, dropping sharply as the speeds increase from 8 to 32 km/h (5 to 20 mph) and then leveling off. The initial drop in operating cost becomes much less pronounced as the GVW increases.

Because the impact on pavement is not taken into account, trucks with lower operating costs present the highest overall savings. The 2-S1-2-2 remains the least efficient of all six truck configurations. The 3-S2-4-4 also loses the advantage of having a higher number of axles, and becomes a less attractive alternative because of higher operating costs, in part because of the much larger number of tires. The double trailers, 3-S2-4 and 3-S3-5, result in better overall savings. The range of speeds over which the savings are achieved is relatively narrow. The cost curves do not cross the $500 mark until truck speed reaches 40 km/h (25 mph) and a GVW of 68,000 kg (150,000 lb) for the 3-S2-4 and a 48 km/h (30 mph) speed and 77,000 kg (170,000 lb) GVW for the 3-S3-5. The single trailer semi-trailer truck results in the largest overall savings over the broadest range of speed and GVW, indicating that semi-trailer trucks (3-S2 and 4-S3) traveling at speeds of 24 to 40 km/h (15 to 25 mph) (speed being constrained as a result of surface condition) with a GVW range of 45,000 to 73,000 kg (100,000 to 160,000 lb), present the lowest overall operating cost. At higher loads, such as in the 91,000 kg (200,000 lb) range, the tandem trailers become the superior truck configuration.

The comparison with existing trucks was made by computing the ratios of total costs to the costs of presently operating farm tractors. The results indicate savings ratio of 4 to 5 times for truck speeds of 16 to 40 km/h (10 to 25 mph) and GVW of 41,000 to 68,000 kg (90,000 to 150,000 lb). Such savings in operating costs of the 3-S2 and 4-S3 over present-day trucks (about 4 times) and farm tractor-wagons (about 5 times), strengthen the argument in favor of letting some rural roads deteriorate or turning them into low-maintenance gravel roads.



Note: 1kg = 2.2 lbs
1km/h = 0.625 mph

FIGURE 4 Vehicle operating cost as a function of speed and gross vehicle weight for Truck Configuration 4-S3.

Strategy 3: Increasing Pavement Thickness

This scheme considers the effects of increasing pavement thickness on the total cost for each of the six truck configurations. The first scenario assessed the impact the different trucks have on road damage and associated added costs, based on the assumption that the road would be maintained according to previous county practices. The road variable maintenance cost was estimated using 5,000 yearly applications of ESALs and the remaining life of the pavement. This scenario consists of upgrading the existing pavement by adding an additional 6 in. of pavement, thus lengthening the lifetime ESAL loading of the road to 500,000 applications. Assuming a 20-year life, the additional 6 in. of pavement would withstand 25,000 ESAL applications per year. Although the pavement life data were based on Baumel's interview with county engineers (*22*), admittedly these are simplifying assumptions that may not be fully supported by real-life performance data.

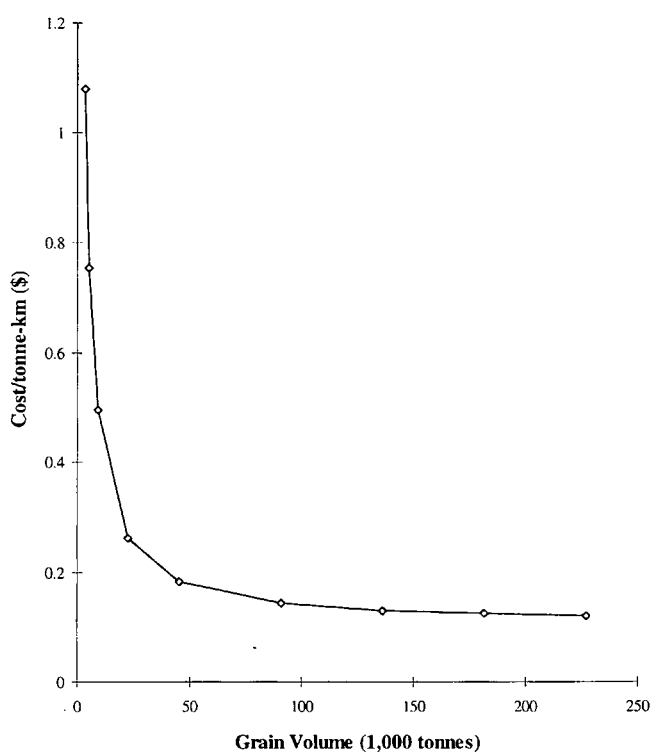
When restricted to the transportation of a single farm's production, the cost of upgrading the road represents a dramatic increase in the road maintenance cost, completely overwhelming the cost of the relative road damage inflicted by individual trucks. The cost of shipping jumps to more than $5/ton-mile. Thus, upgrading the road at the low volume of traffic generated by a single farm is hardly justified. The next step was then to increase the volume of grain shipped to determine the amount of traffic at which the cost of increasing road thickness would be justified. The dramatic effect of increasing grain volume on the resulting decrease in cost per ton-mile for a 68,000-kg (150,000-lb) 3-S3-5 truck combination displayed to scale is shown clearly in Figure 5. The drop in cost per ton-mile as the volume increases from 3,600 tonnes (4,000 tons) to 45,000 tonnes (50,000 tons) is steep and becomes minimal beyond the 90,000 tonnes (100,000 tons) mark.

Different trucks reach a minimum at quite different volumes of grain. If the $0.2/tonnes-km is considered a minimum mark, the results show that the cost of most trucks will cross that mark at about 90,000 tonnes (100,000 tons). Furthermore, as mentioned earlier, the HRB maintenance costs equation resulted in overall VOC overestimates. Thus, the ton-mile cost shown in Figure 5 is an overestimate by a factor of about 4 or 5 cents. This, of course, means that the ratios of costs for heavy vehicles versus conventional vehicles shown are conservative. Cost ratio calculations show that savings of 3 to 4 times over farm tractors begins at 45,000 tonnes (50,000 tons) and increases to 4 and 5 times for volumes just over 90,000 tonnes (100,000 tons).

The volume of grain that would justify an increase in pavement thickness is about 90,000 tonnes (100,000 tons). If this value is to be expressed in terms of an "average farm production," it is roughly equivalent to the total output of 143 average-size farms. Such volumes are common for shipments between country and terminal elevators.

Sensitivity to Distance: Hauling 700 Tons Over a 10- to 200-Mile Range

The three previous scenarios indicated the possibility for important savings over present-day trucks in the farm-to-country-elevator market. In the present scenario, sensitivity to distance is analyzed to assess how the comparative advantage of different truck configurations would change as the hauling distance is increased from the original 16 to 320 km (10 to 200 mi), by 16-km (10-mi)



Note: 1 tonne = 1.1 ton

FIGURE 5 Cost per tonne-km as a function of grain volume for a 3-S3-5 68,000-kg (150,000-lb) truck.

increments. Savings over the longer distances are relevant because the number of transhipments between country elevators and elevators serviced by unit trains is on the increase. The changes in total cost per ton-mile as both the GVW and the distances traveled are allowed to vary for 3-S3-5 truck configurations are shown in Figure 6.

As the GVW increases, the cost curves follow the pattern already described in the first scenario, declining until they pass through a minimum before increasing again. The effects of increasing the distance are similar for all six trucks, with different degrees of importance depending on the type of truck configuration. First, the total cost per ton-mile drops steadily as the distance increases—but this effect tapers off relatively quickly. Cost reductions are modest beyond 80 to 100 km (50 to 60 mi), irrespective of the truck configuration or GVW. Second, the decrease in total cost per ton-mile with distance is more pronounced the farther the distance from the GVW that produces the minimum total cost for a specific truck configuration. Put another way, this means that at the configuration and GVW that results in the minimum total cost for each of the six truck configurations, the impact of increasing the shipping distance on the cost per ton-mile is minimal.

Overall, the 4-S3 and 3-S3-5 trucks offer the widest range of GVW over which lower total costs per ton-mile can be achieved. Both these trucks have the lowest costs for a range of truck weights beginning at about 45,500 kg (100,000 lb) and a distance of 16 km (10 mi). The breadth of the distance and GVW ranges over which the 4-S3 and 3-S3-5 trucks reach lowest costs per ton-mile makes them the more appropriate format of all six truck configurations, whereas the 2-S1-2-2 truck remains the less suitable.

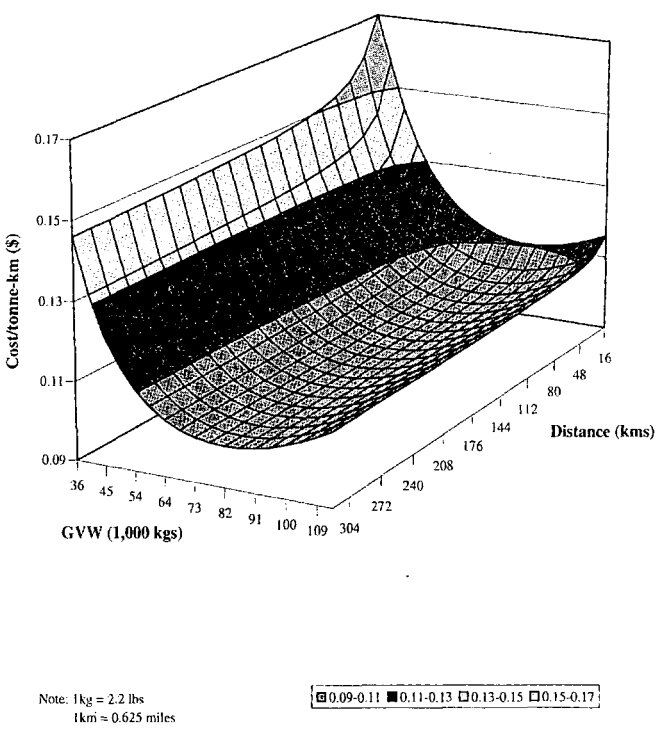


FIGURE 6 Total cost per tonne-km as a function of distance and gross vehicle weight for Truck Configuration 3-S3-5.

The ratio of total cost to today's three representative trucks was again computed for a distance of 80 km (50 mi) to see whether the comparative advantage of the new trucks changes as the shipping distance increases. The benefit margins increase with respect to the 17,000-kg (38,000-lb) farm tractor-wagon combination and now stand at slightly more than 5.1. The benefit margins at 80 km (50 mi), however, do drop slightly with respect to the 14,000-kg (30,000-lb) straight truck as they stand now at close to 3.4 [down from 3.8 for a 16-km (10-mi) distance] and down to about 2.1 from 2.3 with respect to the 24,500-kg (54,000-lb) tandem truck. Despite the decrease, the six new truck configurations would present substantial savings over the present-day trucks for moving grain some 80 or 96 km (50 or 60 mi) between country and terminal elevators or transshipping grain from country elevators to ones served by unit trains.

Geometric and Bridge Costs

This analysis did not include any cost adjustments for geometric considerations. All six truck configurations were restricted to a 2.45-m (8-ft) width limit mainly to avoid having to deal with road widening because of trailer width. Also, the slow speed at which these trucks will operate reduces the need for pavement widening on curves until a curve radius of 10 or 11 degrees is reached, after which an extra 0.61 m (2.0 ft) will need to be added.

Given the relatively short spans of most bridges in rural areas, adding the annualized cost of upgrading bridges on a selected network of high-density freight transportation should not alter in any fundamental way the basic findings presented here. Hamilton County has a total of 31 bridges, with an average size of 73 mi^2 (785 ft^2), and only 3 of those have a less than 36-tonnes (40-tons) GVW rating. The Federal Highway Administration bridge construction unit costs per square foot for the federal-aid system for the state of Iowa is estimated at $38 dollars for 1987 (*25*), accounting for labor, material, and equipment costs. Assuming that all bridges were to be rebuilt, the total cost for Hamilton County would amount to $1 million. This is a very small amount in comparison with the savings that new truck configurations would achieve.

Institutional and Operational Considerations

A road network connecting local country elevators to terminal elevators will likely cross many county jurisdictions. This will require cooperation and coordination on a regional (or multicounty) level. On the state level, a revision of legislation will be needed to adopt flexible standards to accommodate a diversity of transportation needs on local highways. Changes would also be needed in the present maintenance policies from a "maintain as is" approach to one that will allow some roads to deteriorate from paved roads into low-maintenance gravel roads.

Some of the money saved from reduced operating costs could be funneled back into the maintenance of the heavy-truck network. Funds could be collected using the issuance of permits. Furthermore, as heavy truck traffic becomes restricted to a clearly defined network, there will be a reduction of truck traffic on other rural roads, thus reducing the maintenance costs on other parts of the road system.

In addition to new truck size and weight legislation, there will be a need to reclassify the existing roads on which the heavier trucks will be allowed to travel. There are two options: the network can either be shared by trucks and the general public or be used exclusively for trucks.

Given the short distance from farm to local elevator and the volumes of expected traffic on particular links, it might prove feasible to leave gravel truck roads open to the public depending on the density of the network of roads from farms to elevators. The general public traveling on these roads might incur slight inconvenience because of reduced rideability, slower speeds, and increase in vehicle operating costs caused by gravel. There are also some safety concerns when sharing roadways with heavy trucks. These however are somewhat mitigated because trucks will be driving at relatively slow speeds. Also the total number of miles traveled by trucks is actually reduced (because of the lower number of trips), thus reducing the potential for conflict with general automobile traffic.

The lengths of roads connecting country elevators to terminal elevators and the potentially higher traffic, as well as the need for all-year accessibility, makes transforming them into a higher standard (thicker pavement) exclusive (or private) roads an attractive alternative. As some roads are taken out of the present system and converted into exclusive truckways, the reduced mileage of roads will pose some inconvenience to the general public as some private automobiles will have to take longer roads and incur slight increases in travel time and costs. However, given the density of the present rural road network, the effects of choosing alternate routes should be minimal. Another possible alternative would be to reclaim the rights-of-way of abandoned railroads and transform them into exclusive truckways.

The introduction of the new truck configurations might lead to the consolidation of the elevator-terminal system. Because the benefits of using heavier trucks are even greater on longer distances, this could lead to the bypassing (and eventual elimination) of local elevators as grain is hauled directly to terminal elevators.

The new truck configurations, save for the tridem axle, are not very different from today's trucks. The engine sizes required to operate these heavy trucks at relatively slow speeds are well within the limits of presently manufactured engines. The upgrade from present-day trucks to the new configurations should not constitute a major expense increase to truck operators and owners (farmers or seasonal grain-hauling contractors). The larger trucks would cost less per unit of hauling capacity and would require less maintenance (also per unit of hauling capacity) than the smaller ones. Furthermore, the potential for large savings in truck operating costs should entice truckers to switch their fleets to the new configurations.

The tare weights of the new truck configurations are well below existing present highway weight limits. Thus, driving empty trucks between market niches (such as from hauling corn in Iowa to hauling wheat in Minnesota) should pose no problem for the Interstate and other federal-aid primary highways.

POSSIBLE PATHWAY FOR CHANGE

The results of this analysis strongly suggest that the potential for important savings could provide ample incentive for implementing alternative truck and highway configurations, similar to those described here, in one or more grain-hauling markets, if the institutional barriers could be overcome. A possible pathway for change from today's truck system into a more productive system could consist of the following steps:

1. Multicounty or state-level legislation would be adopted to increase the allowable truck GVW over a defined network of roads connecting farms to local country elevators;
2. Current pavement maintenance practices would be changed from a "maintain as is" policy to letting some of the local roads connecting farms to country elevators deteriorate;
3. As the system of slow-moving heavy trucks on gravel roads proves to be a reasonable alternative for serving farm to country elevators at lower overall costs, it would be reasonable to start planning for the expansion of such services. Given the higher volume of grain to be shipped between elevators as well as the need for year round, all-weather accessibility, the cost of upgrading (by increasing pavement thickness) a network of roads connecting country elevators to terminal elevators could be justified based on the savings.

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