

Approximation Equations for Costs of Rail, Trailer-on-Flatcar, and Truck Intercity Freight Systems

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This paper presents equations that approximate the fully allocated and variable costs contained in the Interstate Commerce Commission cost tables for rail-carload, trailer-on-flatcar, and truck intercity freight movements. These equations were developed to enable the user to approximate the costs quickly and easily. They should be useful in initial studies of costs where the exact values are not needed, such as in consideration of rate changes, studies of profitability, and general intermodal comparisons. The equations were used to develop estimates of cost for complete shipper to receiver shipments via the three carriers to illustrate general properties of the carriers, individually and with respect to one another.

The cost characteristics of rail-carload, trailer-on-flatcar (TOFC), and common-carrier-truck intercity freight systems, as estimated by the Interstate Commerce Commission (ICC), are discussed for two purposes: (a) to make available approximation equations for the ICC costs, which are in tabular form, and (b) to compare these costs, individually and with one another.

There are several reasons for using the ICC cost tables. Because they are in the public domain, costs estimated by using them have none of the problems associated with costs estimated by using proprietary methods. The ICC cost tables give estimates that are useful for many transportation-analysis purposes, their value in large measure being derived from the fact that they are used by regulators as a lower bound on the prices that carriers can charge. The fully allocated costs are somewhat analogous to average total costs, and thus also provide a useful measure of cost. The ICC costs are also useful to a shipper engaged in a rate negotiation with a carrier, as a means of estimating the cost to that carrier of providing the service in negotiation. These cost estimates may also be useful to carriers who wish to obtain estimates of the ICC-based costs for particular movements. Such estimates would be useful in studies of the profitability of various movements, as indicators of the commission's potential reaction to a rate change request, and as a basis for comparison of a carrier's true (i.e., internally developed) costs with those of the average carrier.

Balancing the advantages of the ICC cost tables is that the tables themselves are cumbersome to use and that it is difficult to obtain any general picture of cost characteristics from them. Therefore, analytical relations that approximate these tabular costs can be used advantageously, not only to simplify the computations, but also to gain a general understanding of the basic functional relations among the many variables that affect a carrier's costs. The relative costs of rail, TOFC, and road transport depend on a number of characteristics of the shipment and the carrier, such as the distance of the movement, the density of the material being shipped, the total weight of the shipment, the circuitry of the routes, and the extent of empty versus loaded distance traveled.

In the following sections of this paper, we will discuss the cost characteristics of each of the freight systems

individually, compare these characteristics, and make several comments pertinent to freight systems in general. The details of the cost-estimating equations are given in detail.

RAIL CARLOAD

Rail cost and performance will be illustrated for the two most common carriers of general-merchandise freight: unequipped and equipped (sometimes called damage-free or cushion-underframe) general-service boxcars. Although such cars have a wide range of sizes, capacities, and equipment configurations, we will model a typical car having a 59-Mg (approximately 65-ton) weight capacity and a volume capacity of about 139 m³ (4900 ft³). The costs are derived from the ICC statement, Rail Carload Cost Scales 1973 (1), one of a series published annually, which contains, by region, scales showing variable and fully allocated costs as a function of short-line rail distance and weight of load. The costs are given in three forms: (a) a summary table of average regional costs; (b) a breakdown of these unit costs into terminal and line-haul components, with the line-haul component further broken down into way trains and through trains; and (c) a detailed table that contains, for average trains, way trains, and through trains, by car type, variable and constant terminal and line-haul costs on a car-mile and hundredweight-mile basis. In addition to these three basic tables, provision is made to allow adjustment of average costs for situations in which it is known that operational procedures, such as circuitry or empty-return ratio, are different from regional average procedures.

In this paper we illustrate costs for ICC region 3, the official territory of which includes those states east of Wisconsin and Illinois (including a portion of Illinois) and north of Kentucky and North Carolina (excluding a portion of Virginia). The costs of providing basic rail boxcar service in the region, as computed from the ICC cost data, are summarized in Figure 1 for equipped and unequipped cars for several distances as a function of shipment weight. The cost of moving a car is the largest portion of any shipment cost, and marginal increases in the net load of the car have a small effect on total shipment costs.

Cost-Estimating Procedure

The basic rail-boxcar cost-estimating procedures are as follows.

1. Determine shipment characteristics:

- S = shipment weight (cwt);
- L = shipment distance (actual miles)—(if this is not available, reasonable estimates are 1.25 times great-circle distance or 1.18 times rail short-line miles for boxcar movements, 1.09 times rail short-line miles for TOFC movements,

and 1.20 times great-circle distance or 1.06 times highway rate-making miles for truck movements);

D = commodity density (lb/ft³);

t = type of rail car used; and

a = highway-access coefficient [(a) 0, indicating highway access at neither origin nor destination; (b) 1, indicating highway access at either origin or destination, but not both; and (c) 2, indicating highway access at both origin and destination].

(SI units are not given for the variables in these equations, inasmuch as they were derived for U.S. customary units.)

2. Compute number of rail cars required for shipment:

$$n_d = (100S/0.9V) \quad (1)$$

where n_d = volume requirement and V = volume capacity of equipment used (a typical value is 4900 ft³).

$$n_s = (S/W) \quad (2)$$

where W = weight capacity of equipment used (a typical value is 1300 cwt). If n_s or n_d are not integers, they are rounded to the next higher integer.

$$n = \text{Max } (n_d, n_s) \quad (3)$$

3. Select applicable cost formula and compute cost: The basic cost equation has the form

$$C_l = B_l n + 0.000\ 36S + L(E_l n + 0.000\ 148\ 2S) \quad (4)$$

where B_l and E_l are parameters that vary with car type. The variable line-haul cost (c_l) is given by

$$c_1 = 116n + 0.000\ 36S + L(0.317\ 35n + 0.000\ 148\ 2S) \quad (4a)$$

and

$$c_2 = 116n + 0.000\ 36S + L(0.422\ 49n + 0.000\ 148\ 2S) \quad (4b)$$

for unequipped and equipped general-service boxcars respectively. The fully allocated line-haul cost (c'_l) is given by

$$c'_1 = 116n + 0.024\ 46S + L(0.317\ 35n + 0.000\ 286\ 1S) \quad (5a)$$

and

$$c'_2 = 116n + 0.024\ 46S + L(0.422\ 49n + 0.000\ 286\ 1S) \quad (5b)$$

for unequipped and equipped general-service boxcars respectively. The variable highway-access cost (h_s) for rail boxcar is given by

$$h_c = a(4.628S^{0.465} + 0\ 135\ 8S) \quad (S < 100) \quad (6a)$$

$$h_s = a(0.633\ 8S - 0.001\ 454\ S^2) \quad (100 \leq S < 200) \quad (6b)$$

$$h_s = a(0.474\ 8S - 0.000\ 659S^2) \quad (200 \leq S < 300) \quad (6c)$$

$$h_s = a(0.363S - 0.000\ 286S^2) \quad (300 \leq S < 437) \quad (6d)$$

$$h_s = a(0.238\ 1S) \quad (S \leq 437) \quad (6e)$$

The fully allocated highway-access cost (h'_s) for rail boxcar is given by

$$h'_s = 1.11(h_s) \quad (7)$$

The total rail-boxcar system cost (c) is the sum of the line-haul and highway access costs (dollars per shipment).

Adjustments to Basic Procedure

Intuitively, we would expect the many different sizes, weights, and configurations of rail cars to have wide variations in cost characteristics. The two rail cars for which cost data are given above, unequipped and equipped general-service boxcars, are in the middle range of ranking by car costs. The least expensive to operate are large liquid tank cars, and the most expensive (depending on distance of shipment) are several types of special-service cars, such as refrigerated cars, special-service boxcars, and special-service gondolas. It is important to keep these variations due to car type in mind when analyzing specific commodity movements.

The cost characteristics of different types of rail cars can be taken into account by substituting for the basic coefficient values of Equation 4. Table 1 presents coefficient values for B_l and E_l , the two coefficients that vary with car type. The wide variation among car types in weight and volume capacity requires that these characteristics be determined for each individual situation.

Another major variation in cost for which provision can be made through use of the ICC cost data is the effect on total shipment cost of variations in frequency of intermediate yardings. These may be of three types: (a) an interchange movement between two railroads, (b) an intertrain switching between trains of the same railroad company, or (c) an intratraining switching of cars of the same train. The ICC assumes that an intertrain or intratraining switching occurs, on the average, about every 322 km (200 miles) (2). For example, there would be five intertrain or intratraining switchings in a

Figure 1. Rail carload cost as a function of shipment weight and distance.

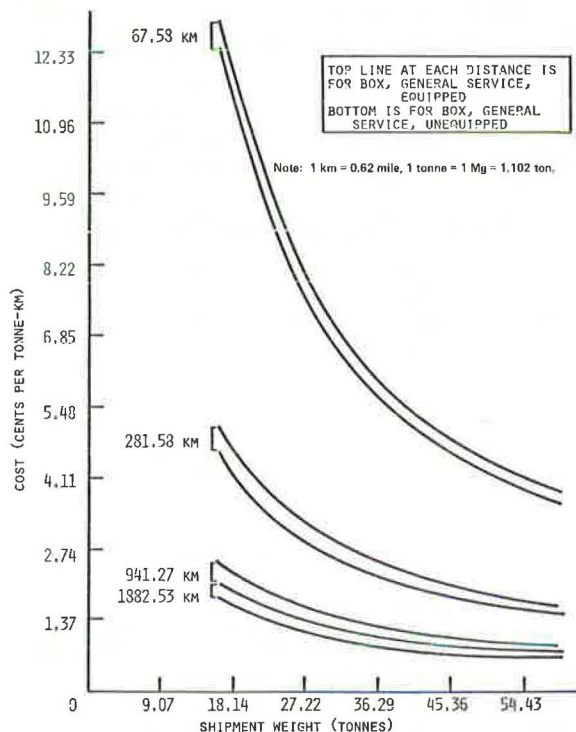
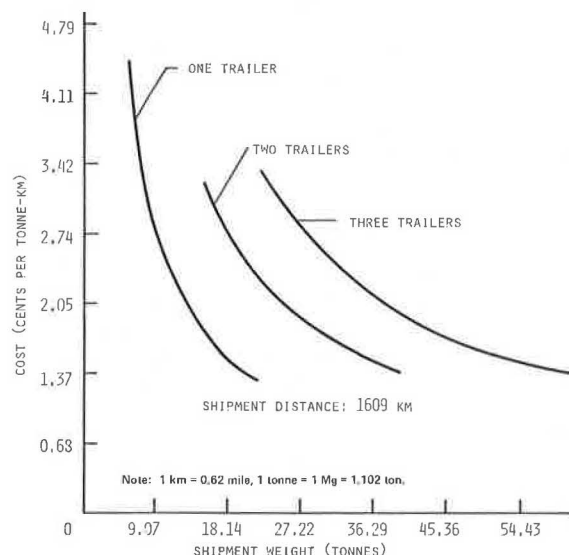


Table 1. Coefficient values of common railcars.

Car Types	B ₁	E ₁	Car Types	B ₁	E ₁
Unequipped general box	116	0.317 35	Mechanical meat refrigerator	83	0.564 99
Equipped general box	116	0.422 49	Mechanical other than meat refrigerator	83	0.535 08
Special box	125	0.482 18	Nonmechanical meat refrigerator	83	0.532 85
General gondola	125	0.366 45	Nonmechanical other than meat refrigerator	83	0.517 25
Special gondola	125	0.428 81	38 to 72 kL (10 032 000 to 19 008 000 gal) tank	83	0.538 61
Open general hopper	125	0.369 58	106 to 121 kL (27 984 000 to 31 944 000 gal) tank	83	0.615 66
Open special hopper	125	0.394 23			
Covered hopper	125	0.429 81			
Stock	125	0.384 86			
General flat	125	0.378 57			

Figure 2. TOFC cost as a function of shipment weight and number of trailers required.



1600-km (1000-mile) haul, resulting in an average distance between such switchings of about 269 km (167 miles). There is no explicit statement of the average frequency of interchanges. Calculations based on the average cost of each interchange in official territory, however, indicate an average frequency of one such interchange about every 965 km (600 miles). The cost difference among different intermediate yarding frequencies is substantial, especially for longer hauls. For example, over a 1600-km (1000-mile) haul, the unit cost difference for a shipment of about 23 Mg (25 tons) would be more than \$5.50/Mg (approximately \$5/ton).

The calculation of shipment costs for other than average intermediate switching conditions is straightforward. The cost estimated by the basic rail formulas includes the cost of average interchange and intermediate switching conditions. If the analyst knows that the movement being costed has other than average interchange switching, he or she may proceed as follows. (This example is for unequipped general-service boxcars.) The cost for x interchanges is given by

$$c_x = (36.54x - 0.066\ 69L)n \quad (8a)$$

and the cost for y intermediate switchings is given by

$$c_y = (12.04y - 0.060\ 17L)n \quad (8b)$$

The appropriate value (c_x or c_y) should be added to the cost computed by using the basic procedure.

TRAILER ON FLATCAR

TOFC costs are developed based on information in the Rail Carload Cost Scales 1973 (1). Cost scales are not presented, however, and the method of computation is quite different. Costs are computed on the basis of an assumed cost per ton mile carried, and other operational characteristics of TOFC are given on a regional average basis. This method allows the analyst to explicitly vary such operational characteristics as the number of trailers required for the shipment being costed, the number of trailers assumed to be riding on each rail flatcar, and the weight of the shipment. If information on these characteristics of the shipments is not available the analyst can use regional average data.

There are several TOFC plans, with variations in the degree to which responsibility for a shipment is divided between the railroad and the shipper. We will illustrate costs for plan 2, in which the railroads perform the entire service from consignor to consignee. Figure 2 shows cost per shipment for various shipment weights for distances of about 1600 km (1000 miles). The cost curves of Figure 2 illustrate three interesting characteristics of TOFC costs: (a) the significant contribution to total cost of terminal-related costs, (b) the influence on total cost of the number of trailers required to carry any given load, and (c) the relatively minor influence on total cost of the load carried in any given number of trailers. The second of these, that the number of trailers required for a movement, rather than the absolute size of the net load, is the primary determinant of cost, can be confirmed by inspection of single and double-trailer cost curves for movements of the same weight and distance. For example, a shipment of about 22 Mg (488 cwt) moving about 1600 km (1000 miles) in a single trailer has total shipment cost of approximately \$465. In a double trailer, the same shipment costs approximately \$820. Finally, the third point, that (as for rail-boxcar movements) the marginal effect of increasing shipment weight is minimal, can be observed by inspection of any single cost curve. For example, a three-trailer movement of about 22 Mg (488 cwt) moving about 1600 km (1000 miles) has a total shipment cost of approximately \$1200 dollars, but increasing the load to about 60 Mg (1317 cwt) increases the total shipment cost to only approximately \$1304, an increase in cost of slightly more than 11 percent.

Cost-Estimating Procedure

The basic TOFC cost-estimating procedure is as follows.

1. Determine shipment characteristics in the same way as for rail car.
2. Compute number of TOFC trailers required for shipment by using Equations 1, 2, and 3. (For TOFC trailers, typical values are $V = 2550\text{ ft}^3$ and $W = 490\text{ cwt}$.)

3. Select applicable cost formula and compute cost: The variable cost (c_n) is given by

$$c_1 = 193 + 0.001 \text{ 18S} + (0.206 + 0.000 \text{ 136 7S})L \quad (n = 1) \quad (9a)$$

$$c_2 = 378 + 0.001 \text{ 18S} + (0.379 + 0.000 \text{ 136 7S})L \quad (n = 2) \quad (9b)$$

$$c_3 = 566 + 0.001 \text{ 18S} + (0.585 + 0.000 \text{ 136 7S})L \quad (n = 3) \quad (9c)$$

$$c_4 = 750 + 0.001 \text{ 18S} + (0.758 + 0.000 \text{ 136 7S})L \quad (n = 4) \quad (9d)$$

and the fully allocated cost (c_n') is given by

$$c_1' = 193 + 0.025 \text{ 28S} + (0.206 + 0.000 \text{ 262 2S})L \quad (n = 1) \quad (10a)$$

$$c_2' = 378 + 0.025 \text{ 28S} + (0.379 + 0.000 \text{ 262 2S})L \quad (n = 2) \quad (10b)$$

$$c_3' = 566 + 0.025 \text{ 28S} + (0.585 + 0.000 \text{ 262 2S})L \quad (n = 3) \quad (10c)$$

$$c_4' = 750 + 0.025 \text{ 28S} + (0.758 + 0.000 \text{ 262 2S})L \quad (n = 4) \quad (10d)$$

both in dollars per shipment.

Adjustments to Basic Procedure

Interchange and intermediate switching adjustments are similar to those used for rail-carload costs. The cost for x interchange switchings is given by

$$c_x = (30.79x - 0.042 \text{ 66L}) (n/2) \quad (11a)$$

and the cost for y intermediate switchings is given by

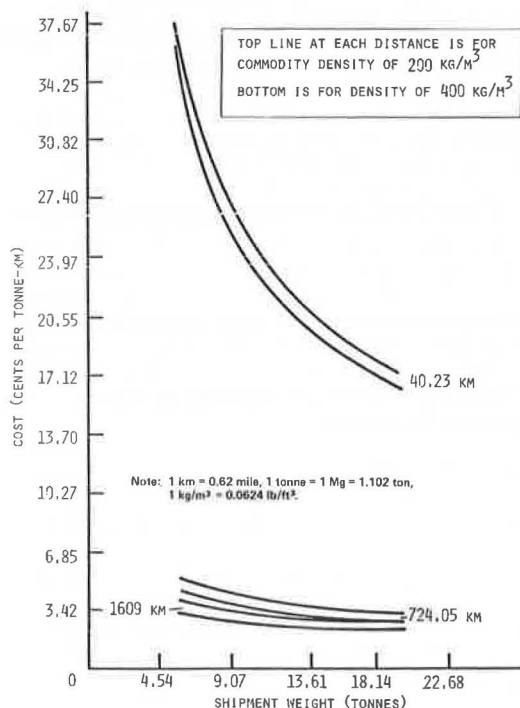
$$c_y = (10.14y - 0.033 \text{ 610L}) (n/2) \quad (11b)$$

where, if $(n/2)$ is not an integer, it is rounded to the next higher integer.

HIGHWAY COMMON CARRIER

Highway, intercity freight-system costs are estimated

Figure 3. Highway common-carrier cost as a function of shipment weight and distance.



by using the ICC statement, Cost of Transporting Freight by Class 1 and 2 Motor Common Carriers of General Commodities 1973 (3), which gives several tables of updated unit costs and operational characteristics that allow the analyst to develop cost scales for various shipment weights or weight brackets. As is the case for rail carload and TOFC, cost estimates are given for various regions or territories of the United States. For consistency, highway costs are here estimated for the eastern and central territory, which is similar to the rail industry's official territory, although it includes more of Illinois and none of Virginia.

There are two significant differences between the highway system cost-estimating procedures and those described above for rail boxcar and TOFC. First, it is not necessary that the analyst have explicit knowledge of the physical and operational characteristics of the highway service being costed. Data are given for a wide range of shipment weights and distances, and the assumption implicit in the associated unit costs is that the shipment moves in a service having average characteristics. This might mean, typically, that a small shipment would be first handled in local pickup-and-delivery service by a small vehicle suited to such operations and then be consolidated with other shipments with common destinations in a larger over-the-road vehicle for the intercity line-haul portion of the total movement.

The second difference, which is related to the first, is that in highway costing the density of the shipment being costed is explicitly taken into account. Since the capacity of a vehicle is limited by not only weight but also by volume characteristics, the highway costing technique, which does not include explicit determination of the number and type of vehicles required for a given shipment, must include some other method for taking variations in spatial occupancy of different commodities into account.

Figure 3 shows the cost characteristics of the highway mode. Cost is given by a band, rather than by a single curve, that shows the effect of different densities of commodities being shipped. The lower line at each distance is for the higher density commodity, and the higher line is for the lower density commodity. Although, intuitively, we would expect density to have effects on platform operations, on the pick-up and delivery portions of terminal costs, and on line-haul cost, it is taken into account in the source publication (3) by a weighted factor adjustment to the line-haul unit costs. As might be expected, cost decreases with increasing shipment weight, in part because of efficiencies associated with larger vehicles and in part because of a reduction in shipment platform handling by the carrier. (The probability that a shipment will be picked up at the consignor's dock and transported in a single truck to the consignee's dock without intermediate terminal handling by the carrier increases as the shipment size increases.) The rate of decrease in unit cost, however, becomes much lower above a shipment weight of approximately 18 Mg (399 cwt). One possible explanation is that this is the point beyond which vehicle size cannot be further increased so that the economies previously realized by increasing vehicle size are no longer available.

Cost-Estimating Procedures

The highway common-carrier cost-estimating procedure is as follows.

1. Determine shipment characteristics in the same way as for rail car.
2. Select applicable cost formula and compute cost:

The variable unit cost (C_s) is given by

$$C_s = 924S^{-0.537} + (8.8286 + 0.16901L) [0.855 + 1.32 \exp -0.1447(D - 2.5)] + (0.29293S^{-0.736})L \quad (S < 100) \quad (12a)$$

$$C_s = 70.51 - 0.2907(S - 100) + (12.107 + 0.18098L) [0.855 + 0.68 \exp -0.16176(D - 7.5)] + [0.00988 - 0.0000638(S - 100)]L \quad (100 \leq S < 200) \quad (12b)$$

$$C_s = 41.44 - 0.1317(S - 200) + (6.25 + 0.17275L) [0.855 + 0.68 \exp -0.16176(D - 7.5)] + [0.0035 - 0.0000299(S - 200)]L \quad (200 \leq S < 300) \quad (12c)$$

$$C_s = 28.27 - 0.0571(S - 300) + (2.706 + 0.1509L) [0.855 + 0.68 \exp -0.16176(D - 7.5)] + 0.00051 \quad (300 \leq S < 437) \quad (12d)$$

$$C_s = 23.153 + 0.13406L + [0.10261 \exp -0.16176(D - 7.5)]L \quad (S \leq 437) \quad (12e)$$

The fully allocated unit cost (C'_s) is given by

$$C'_s = 1.11C_s \quad (13)$$

The total highway common-carrier variable and fully allocated costs (C_s and C'_s respectively) are given by

$$C_s = c_s S / 100 \quad (14a)$$

and

$$C'_s = c'_s S / 100 \quad (14b)$$

all in dollars per shipment.

Accuracy

The truck costs estimated by equations are not as good a fit as those for the rail modes. The errors, at representative shipment weights and distances, are given in Table 2. It is necessary, therefore, that an analyst using these equations be aware of the potential errors involved, although for the most common shipment distances and weights, the total cost error is less than 5 percent.

COST UPDATING

Although the costs given above are useful in providing information on general cost behavior in the study year (1973), most applications would require more current estimates.

One way of updating is based on the Bureau of Labor Statistics (BLS) indexes of rail freight costs. (The BLS term cost corresponds to our term rate—the price charged to shippers by transportation firms—rather than to our cost—the cost to transportation firms of providing that service.) For example, in 1973 the index stood at 129.3 (4); its last reported level was 198 (February 1977) (5). If we assume that rate increases mirror increases in carriers' costs, then we can update the 1973 cost estimates presented here by increasing them by the ratio of the current to the 1973 rate index. In the example above, this would mean multiplying the 1973 rail-carload and TOFC cost estimates by 1.53. A similar set of indexes for highway common-carrier costs (rates) is scheduled for release by BLS in 1977.

COMPARISON OF SYSTEMS

In the previous sections, we have presented cost models for the three intercity freight carriers. In this section, we will present a comparison of their characteristics for a few sample origin-to-destination intercity movements, including several levels of shipment size and distance. In all cases, the variable cost will be used.

The TOFC and highway systems as they are described above are capable of providing a direct dock-to-dock service. However, some shippers or consignees do not have direct rail access and, therefore, it is necessary to include in the rail-system cost estimates provision for highway access at either origin or destination or both, if required.

The highway portions of these access segments are assumed to be similar to the pick-up-and-delivery operations included in the highway cost estimation, and their cost is estimated on this basis. The physical transfer of cargo is assumed to be a rail operation. On this basis, access cost at both origin and destination is composed of the origin-and-destination terminal cost included in the highway cost estimates: (a) pick-up and delivery, (b) highway platform handling, (c) billing and collecting, and (d) a rail platform-handling charge estimated at about \$3/Mg (13.6 ¢/cwt)/handling (i.e., at each end) (1, p. 149).

Another factor that must be taken into account before we can make direct comparison among the three intercity freight modes is circuitry, the deviation of the path actually followed by a shipment from some common or reference distance between its origin and destination. In the absence of actual knowledge of this information, we will adopt the results of a recent study (6). Since the typical circuitry values for rail and truck are so similar (1.25 for rail and 1.20 for truck) (and we know that cost estimates may well have variations of the magnitude of the difference between these two circuitry

Table 2. Absolute and percentage deviations of costs estimated by equations according to shipping distance and value.

Shipping Weight (Mg)	40.2 km				644 km				1609 km			
	\$10 to 15		\$20 to 30		\$10 to 15		\$20 to 30		\$10 to 15		\$20 to 30	
	Abso-lute	Per-centage	Abso-lute	Per-centage	Abso-lute	Per-centage	Abso-lute	Per-centage	Abso-lute	Per-centage	Abso-lute	Per-centage
0.169	1.3	8.0	1.3	8.0	1.6	7.6	1.7	8.5	2.3	2.3	8.7	9.3
0.292	0.3	1.3	0.2	0.9	0.2	0.7	0.3	1.0	0.6	0.6	1.5	1.6
0.581	0.6	1.9	0.4	1.3	-0.1	-0.2	-0.1	-0.2	-0.5	-0.2	-0.1	-0.4
1.261	-1.2	-2.5	-1.5	-3.1	-3.2	-4.2	-3.2	-4.5	-3.8	-3.9	-3.4	-3.9
2.921	3.1	4.4	2.4	3.5	-0.2	-0.2	-0.2	-0.2	0.2	—	0.1	—
5.797	17.4	19.8	14.7	17.3	7.7	3.5	7.4	3.8	11.07	10.2	3.0	3.3
11.06	13.1	10.7	12.3	10.6	7.8	2.4	3.2	1.2	28.5	12.2	4.9	2.5
15.39	-7.5	-6.1	-8.2	-7.0	-2.0	-0.1	-7.5	-2.4	13.5	-6.1	1.9	-1.1
19.82	-13.1	-9.6	-13.4	-10.4	-5.7	-1.2	-13.1	-3.4	14.0	-11.4	1.6	-1.6

Note: 1 km = 0.62 mile; 1 Mg = 1.102 tons.

values), we will assume that these systems may be compared on an equal-distance basis.

These assumptions concerning highway access to rail carload and the circuitry of the three systems are included in the cost-estimating procedures given above.

Effect of Distance and Shipment Weight

We are now able to compare the costs per megagram

Figure 4. Comparison of shipper-to-receiver costs for 1609-km shipment distance.

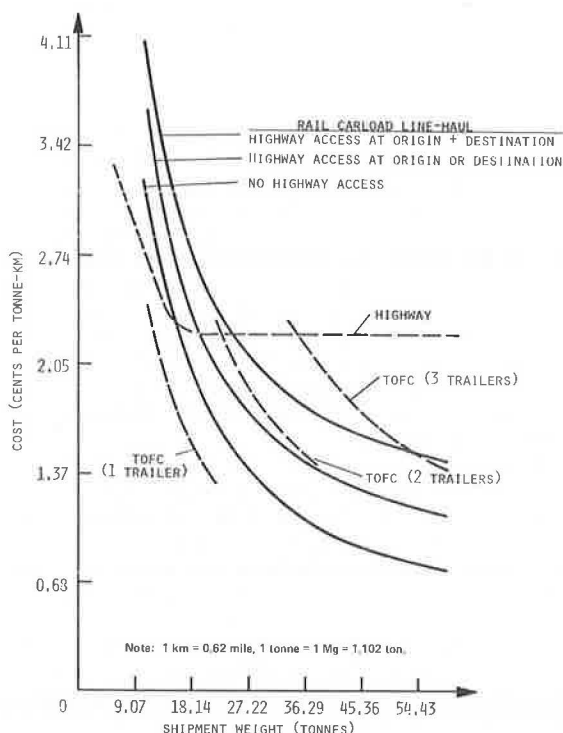
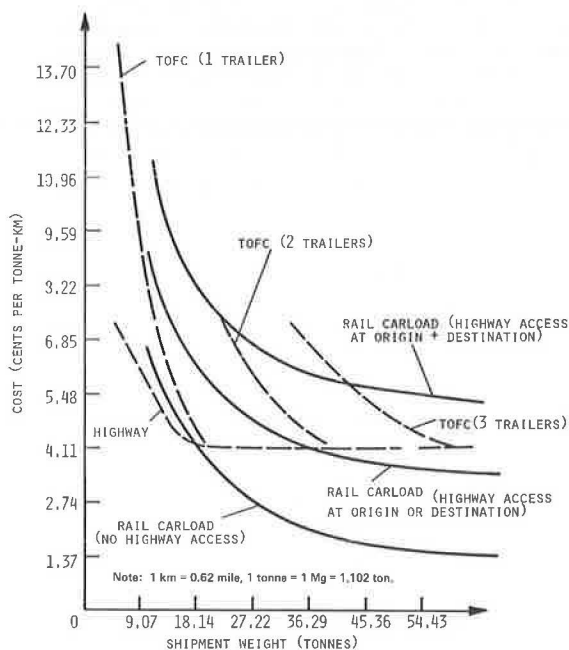


Figure 5. Comparison of shipper-to-receiver costs for 280-km shipment distance.



kilometer of the three systems for the same transport service. Such comparisons are illustrated in Figures 4 and 5 for 1609 and 280-km (1000 and 175-mile) line-haul movements respectively.

Analyzing Figure 4, we observe that truck is the least costly mode for shipments up to about 10 Mg (220 cwt), that TOFC is the least costly from that point up to a full (by weight) trailer load of about 22 Mg (488 cwt), and that relative ranking above that weight depends on whether or not highway access to the rail boxcar system is necessary. If access at either one or neither end is required, then conventional rail is the least costly for loads above about 22 Mg (488 cwt). If, however, highway access service to rail is required at both origin and destination, then TOFC is the low-cost mode for loads up to about 40 Mg (874 cwt) and above about 55 Mg (1220 cwt).

Figure 5 shows that the effect of distance on relative cost ranking is significant. For the shorter distance, the low-cost system is either highway or conventional rail, with the exception of a small region around 22 Mg (488 cwt), within which TOFC is less costly than highway. The relative rank of conventional rail and highway depends again on the extent to which highway feeder service to the rail line-haul is required. If it is not required, then rail is the low-cost system above about 16 Mg (360 cwt), and if it is required at both origin and destination, highway is least costly for all loads.

As we discussed in the section on TOFC costs above, drayage cost has an important effect on total TOFC cost levels. The results cited in the example will, of course, vary with changes in drayage, which was assumed here to be at average nonurban area (relatively low) levels.

Effect of Density and Shipment Weight

The assumption that weight, rather than volume, is the limiting characteristic in determining the number of vehicles or containers necessary to carry any given load is implicit in the system comparisons. Thus, a density of about 320 kg/m^3 (20 lb/ft^3) was assumed in the cost calculations. This explains the breaks in the TOFC cost curves: once a single trailer is loaded to its weight capacity, about 23 Mg (about 25 tons), any increase in load requires a second trailer. Similarly, a load of about 59 Mg (65 tons) in a typical boxcar requires a minimum density of about 430 kg/m^3 (27 lb/ft^3). These constraints were not addressed in the examples above, except as they are taken into account in the highway cost scales.

We can perform an analysis that illustrates the extent to which cargo density affects volume occupancy—the number of vehicles required for a given movement of specified weight and density—and, therefore, the density effect on relative cost ranking. The difference between this and the previous cost estimates is that these costs for highway and conventional rail systems were engineered on the basis of costs per basic unit of capacity and then used to determine costs per vehicles required, taking into account both weight and volume limitations of the vehicle used. Assume a load of about 22 Mg (488 cwt)—slightly less than the maximum highway trailer load by weight, trailers in both highway and TOFC service of about 65-m^3 (2300-ft^3) usable capacity (3, p. 23), and a typical rail boxcar of about 139-m^3 (4900-ft^3) usable capacity. For a cargo density of about 178 to 340 kg/m^3 (11.1 to 21.2 lb/ft^3), conventional rail boxcar is least costly for all distances, and TOFC is second least costly above distances of about 640 km (400 miles). For more dense commodities, highway is least costly at distances below about 200 km (125 miles), conventional rail between 200 and 1125 km (125 and 700 miles), and TOFC above

1125 km (700 miles). The higher density, of course, allows a single trailer (either highway or TOFC) to carry the entire 22-Mg (488-cwt) load. We see, then, that the effect of changes in cargo density may (as in our example) change the cost ranking of the three systems for some distance movements.

CONCLUSIONS

In this paper, we have presented cost-estimating equations for the variable and fully allocated costs of providing conventional rail boxcar, TOFC, and highway intercity freight services, based on ICC cost data and models. The paper covers three topics:

1. Presentation of the estimating equations and a comparison with the values obtained from the original ICC cost tables,
2. The basic costs of each mode and some discussion of the sensitivity of each to several different operating policies, and
3. An example comparison of the costs of each mode in the provision of total dock-to-dock freight transport service under various market conditions.

Some important conclusions about the characteristics of these three modes are that

1. The high cost of local access to line-haul facilities (shown here by highway access to rail line-haul) has significance for any multimodal system that includes existing technology and operating policies and specifically, potential improvements in line-haul cost and performance may be more than offset by the costs of local drayage and the transfer between the modes and
2. Variations in cargo density cause substantial variations in system costs, to the extent that the ranking by cost of the three systems may be changed.

Some conclusions about cost estimation in general are that

1. Although the costs given here are reasonable estimates of average costs in 1973 in the Northeast and Midwest regions, they are deficient in the following respects: (a) because of the regional average basis of both unit costs and service units, these costs would not

be a sound basis on which to evaluate specific services in any but the most cursory analysis; (b) the current unsettled status of the rail system in the region might be resolved in such a way that institutional, operational, and managerial changes would cause the costs to become obsolete; and (c) the passage of time lessens the accuracy of any estimates based on historical data and

2. To correct these deficiencies will require research on the basic nature of transport system costs that goes far beyond the original ICC cost studies, which despite their widespread use for determining costs and rates, rely on many assumptions.

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Abridgment

Evaluation of Potential Policies for Intercity Passenger Transportation in Canada

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A quantitative, internally consistent assessment of the impacts of various policy options on national, multimodal, intercity passenger transportation has been studied. The results of the study are summarized in two reports (1, 2).

A multimodal travel demand model was developed to forecast travel by mode between pairs of cities. The model is responsive to (a) modal travel time and service frequency—reflecting the configurations and quality of