THE TON-MILE: DOES IT PROPERLY MEASURE TRANSPORTATION OUTPUT?

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The current unit of transportation, the ton-mile (megagram-kilometer), must be reevaluated. This paper traces the origins and uses of the ton-mile, exposes its shortcomings, and examines its current misuse as a measure not only of tons and miles (megagrams and kilometers) but also of efficiency, competition, and productivity. The use of the ton-mile as a measurement has been responsible for many problems in transportation policies and is probably the principle reason that so much confusion and controversy exist with respect to the national transportation system today. The paper recommends gross freight revenue (or the value of transportation) as a far better measurement because it more accurately reflects the relative worth of the various modes to the national effort of moving goods. It is suggested that the Transportation Research Board address the matter as a problem deserving its full and immediate attention.

•THE TON-MILE (megagram-kilometer), the movement of 1 ton (0.9 Mg) 1 mile (1.6 km), is the most widely accepted unit of transportation output in use today. Yet the ton-mile, along with its relative the passenger-mile, is unfit for many of the purposes for which is is used. Reliance on the ton-mile as a unit of transportation service has been responsible for much of the confusion and controversy that exist with respect to our national transportation system today.

Although the trucking industry has been the most persistent and vocal critic of the ton-mile as a general measure of transportation output in recent years, it was not the first nor the only industry to call attention to its lack of validity for many of the purposes for which it is used.

The origin of this hybrid unit of measurement is unknown. Perhaps (and this is pure speculation) it was used by the Phoenicians, the world's first great traders; or it may have evolved in the Middle Ages when tolls for the use of roads and waterways were common throughout Europe and the Middle East. Among the first recorded references to its use as a measurement of the cost of transportation was that by Stevens (1), who urged government ownership of railroads in 1824: "One ton might be transported 280 miles for 50 cents, which means 0.178 cents per ton-mile." A later reference can be found in Strickland's Report on Canals, Railroads, Roads, and Other Subjects, presented to the Pennsylvania Society for Promotion of Internal Improvements in 1826. The report (1) refers to traffic being conveyed for "less than half a farthing per ton per mile." Latrobe, a civil engineer for the Baltimore and Ohio Railroad, however, is generally credited with originating the ton-mile as the railroad unit of work in 1847 (2).

Perhaps the principal impetus to using the ton-mile as a general measure of transportation came when it was used as a statistical unit by the Interstate Commerce Commission in its First Annual Report on the Statistics of the Railway in the United States for the year ending June 30, 1888. Individual ton-mile statistics were reported not only for each railroad but also for the railroads as a whole, in computations such as "revenue per ton of freight per mile" and "average cost of carrying one ton of freight one mile." The use of these statistics, however, carried the following admonition (3):

> There is, of course, some danger of misinterpreting or rather of misapplying such figures. . . .They are to be accepted as averages and not as an absolute standard. It lies in the theory of averages to eliminate everything that is peculiar; he, therefore, who makes use of an average for any particular problem must modify the standard to allow for what is peculiar in the conditions considered.

The warning was well made because, in the early days of the railroad industry, analysts were well aware of the limitations of the ton-mile as a measure of transportation output. Some authorities seriously questioned its usefulness for any purpose. For example, in 1904 Peabody (4) of the Atchison, Topeka, and Santa Fe Railway said:

> The origin of traffic is so widespread, the volume of traffic so large, and the conditions of traffic so diverse, as to make it manifestly impossible for any general statement to be made within comprehensible limits. . . .In the early days of railroading some man conceived the idea of working out the average earnings per ton-mile—a factor not only useless as conveying any information, but absolutely harmful because of the wrong impression thereby created.

English railroads were particularly apprehensive about the use of ton-mile statistics. In fact, of the 20,768 miles (33 415 km) of track in the United Kingdom, only one road, the North-Eastern with 1,656 miles (2665 km) of trackage, was using the ton-mile at the beginning of the twentieth century. Cecil (4), one of the directors of the London and South-Western Railroad, felt it would not have any "real, practical value on the small system of English railways."

Criticism of the use of ton-mile as a general measure of transportation output has persisted over the years. The use of a related unit, the passenger-mile, to measure the movement of people is as limited as ton-mile to measure output. Economist Barger raised this point in 1951 (5):

> It is argued here that the natural units for measuring transportation service are the passenger and freight ton-mile. . . .[But] an obvious extension of the notion that 16 passengers are not the economic equivalent of a ton of freight leads us to query the appropriateness of treating ton-miles and passenger-miles, respectively, as homogeneous. Certainly the services of transporting a ton of oil in bulk and a ton of package freight over the same distance sell for different prices; moreover, they may involve the use of different amounts of resources.

Another transportation authority, Troxel (6), in discussing transport cost in 1955, expressed similar doubts:

> Although ton-miles may be generally accepted, their conclusions still leave some questions about cost assignments, samplings and output units. . . .Indeed, the organization of transport operations is not much embraced in ton or ton-mile, passenger-mile, or even load units.

Milne (7) pinpointed a basic weakness of the use of ton-mile for general analytical purposes when he made the following observation:

> It is highly misleading to regard all transport facilities as parts of one industry, the transport industry, and as producing homogeneous passenger-miles in the case of passenger transport and homogeneous ton-miles in the case of goods transported.

Milne suggested use of "transport units" and "the train-journey, the bus-journey, the truck-journey, or the aircraft-journey as our unit of output." He also suggested that

these various transport units be kept separate from "the pricing unit," which he called "individual passenger and the individual consignment."

Other economists, too, have had misgivings about the use of the ton-mile. For example, Wilson (8) aptly pointed out: "If one examines some of the principal textbooks in the field of transportation, he will note that the various diagrams that purport to show cost and demand relationships for transportation enterprises do not label the abscissa." Wilson gave as his examples the Economics of Transportation (9) and Increasing Returns in the Railway Industry (10). However, most textbooks seem to agree with Hurst's illogical conclusion (11) that, although the ton-mile "fails to capture some important qualities such as cost, speed, flexibility, and safety... no better measure appears to exist for use in comparing energy efficiencies of different transport modes." Such reasoning is reminiscent of the man who lost his collar button in the bedroom but looked for it in the bathroom because the light was better there. What good are data when they produce unreliable, spurious, and inconclusive results? Quast (12) certainly disagreed with Hurst's assumption that ton-mile is better than nothing, for he stated: "And as between accepting the ton-mile and rejecting economic analysis, acceptance would seem to be too high a price to pay."

Despite these legitimate criticisms, the use of ton-miles for inappropriate purposes persists. Perhaps the greatest shortcoming of the ton-mile for general analytical purposes is that it is not a homogeneous unit. It is merely a physical measurement with all the limitations of such measurements. Thus it is similar to pounds, gallons, and bushels used in other phases of the economy and must be used judiciously. No one would think of comparing goods without recognizing differences in their characteristics. Thus, no one would consider comparing milk with paint in terms of gallons, nor would gallons of paint be added to gallons of milk to measure total output. Imagine comparing the number of tons of steel, aluminum, and magnesium produced per gallon of fuel or per person-hour without taking into account the different characteristics of these metals or computing the output of metals by adding the number of tons of steel, aluminum, and magnesium produced together.

Indeed, supposedly meaningful analyses that are made by using the invalid ton-mile unit create serious problems. Among the more flagrant misuses of ton-miles for analytical purposes are measurements of relative productivity of labor over time and evaluations of the relative efficiency of different modes of transport. In the former case, the errors involve modal as well as intermodal comparisons.

Calculating trends in labor productivity over time by using only the ton-mile produces serious distortions, particularly with respect to railroads. A report of the Task Force on Railroad Productivity (13) devoted an entire chapter to this problem. A synopsis of the chapter follows:

> Conventional and widely used measures of railroad productivity, such as ton-miles per person-hour, indicate that rail productivity has grown at a rate of 5 to 6 percent a year during recent decades, considerably above the average growth of labor productivity in the private economy (3.0 percent) during these same decades. However, by using alternative assumptions and measures (e.g., allowing for changes in the composition of rail traffic), it can be argued that growth in rail labor productivity has been only about 3.7 percent. Capital inputs to the railroad industry have not declined nearly so rapidly as labor inputs, and the indicated growth of rail capital productivity is near zero. When labor, capital, and other inputs are weighed together, total rail productivity may have grown only 1 to 2 percent per year during recent decades. This low level of total productivity growth, considerably below the level of total productivity growth in the private economy (2.5 percent per year), is consistent with the railroads' losses of traffic to other modes and with the low rate of return on investment in railroad property.

However, the remainder of the report leans quite heavily on ton-mile analyses.

In addition, another widespread abuse of the ton-mile as a unit of transportation output is in intermodal comparisons. Currently this unit is being widely used to measure relative energy efficiency of the several modes of transport. To assume that the

average number of ton-miles produced per gallon of diesel fuel or per Btu by the several modes of transport is a proper indication of their relative efficiency is absurd.

The number of ton-miles per gallon of fuel obtained by a given transport mode depends on so many variables that any generalization is bound to be misleading. This is true intramodally as well as intermodally. Some of the reasons that such comparisons are misleading follow.

1. Fuel use varies with the gross weight moved, not with the load carried. Relative fuel efficiency, however, is a factor of the cargo weight to the tare weight of the vehicle.
2. Fuel use varies with the actual distance freight is moved, not with the distance between the points served. This has significance in intramodal and intermodal comparisons.
3. Fuel use by mode varies with the volume of freight to be moved between the same points at a given time and over time.

The effect of carried load to tare weight on fuel consumption can be illustrated by an example using a passenger car: If an automobile that weighs 3,600 lb (1630 kg) empty carries a load of four persons weighing 100 lb (45 kg) each, the carried load is 400 lb (180 kg) and the gross weight is 4,000 lb (1810 kg). However, if the persons carried weighed 200 lb (90 kg) each, the load carried would be 800 lb (360 kg) and the gross weight would be 4,400 lb (1990 kg). The load carried would be twice as much with the heavier persons (800 lb versus 400 lb or 360 kg versus 180 kg), but the total gross weight would be only 10 percent higher (4,400 to 4,000 lb). If the car obtained 10 miles/gal (4.25 km/liter) with lighter persons and 9 miles/gal (3.8 km/liter) with the heavier, the fuel efficiency based on the carried load would be 2 ton-miles/gal (0.3 Mg·km/liter) for the 400 lb (180 kg) and 3.6 ton-miles (0.5 Mg·km/liter) for 800 lb (360 kg). There would be an actual increase in fuel consumption of 10 percent—if we assume that fuel consumption increases in direct proportion to the gross weight of the loaded vehicle—but an apparent increase in energy efficiency of 80 percent in ton-miles per gallon of fuel, based on the carried load.

Obviously, the importance of moving people cannot be determined on the basis of their weight; neither can efficiency. The same principle applies to the movement of freight. A flatbed truck combination carrying steel would have an empty weight of about 13.5 tons (12.2 Mg) and a load of about 23 tons (20.8 Mg), for a gross weight of 36.5 tons (33 Mg). A refrigerated combination carrying Boston lettuce would have an empty weight of about 15.5 tons (14 Mg) and a load of about 10.5 tons (9.5 Mg) for a total of 26.0 tons (23.5 Mg). The gross weight, the weight that influences fuel consumption (all other things being equal) of the combination loaded with steel would be only 40 percent greater than the one carrying lettuce, but its carried load would be 120 percent more.

Because fuel consumption would not increase in direct proportion to the increase in the carried load, the relative number of ton-miles that could be obtained between the same points per gallon of fuel when steel was hauled would greatly exceed those that would be obtained when lettuce was hauled. Nevertheless, steel is hardly a substitute for lettuce, and both must be hauled, regardless of the relative number of ton-miles per gallon.

In addition, the same shipment moving between the same points can produce different ton-mile aggregations, depending on several factors that must be considered when relative energy efficiency is compared. For example, railroad routes between the same points are rarely the same. If two railroads operate between identical points and railroad A operates over a route that is 20 percent longer than that of railroad B, the number of miles when multiplied by the weight of the shipment will result in 20 percent more ton-miles by railroad A in moving the same freight. Yet each railroad would be performing the same function, and, moreover, railroad B might be performing it better inasmuch as it probably would provide faster service at a lower total fuel consumption. The longer haul actually using more fuel would produce a greater rate of fuel efficiency when measured in ton-miles per gallon.

Moreover, circuity has a bearing on relative fuel efficiency in intermodal comparisons. Commenting on this point, Smith (14) wrote:

> The significant factor that has not been considered in any reports to date is that average Btu consumption per net ton-mile alone is not an accurate comparison between water and rail. Water interests have been silent about inland barge and coastwise vessel mileage circuity over rail mileage between common points.

When railway movements are compared to truck movements between the same points the effect of circuity is also significant. Railway routes between the same points are generally longer than highway routes. In some instances, the rail mileage is more than double the highway distance. Thus, on the same shipments between these points, rail ton-miles could be double truck ton-miles on this basis alone.

Generally speaking, railroads can move large quantities of goods between fixed points with a low expenditure of fuel per ton-mile. As the quantity to be moved at a given time declines, however, so does energy efficiency. On the other hand, trucks are relatively small transportation units, and their fuel consumption varies less with changes in volume. The differences in fuel consumption in relation to volume can be illustrated by an example involving passengers: If 1,000 persons wish to travel between two points and all can leave at the same time, a railroad could probably move them with a low consumption of fuel per passenger. However, if the number that could leave at one time dropped to 500, the energy efficiency of the railroad per unit would decline sharply. If only 50 could leave together, buses would undoubtedly be more efficient.

Finally, freight cannot move to and from rail terminals by itself, and cars must be assembled into trains. Both operations require fuel.

Admittedly, because tons, miles, and ton-miles are such misleading measurements of transportation output, an alternative method should and must be developed. The new measurement must be available from current data, reflect the relative importance of transportation to the total gross national product (GNP), and, yet, be adaptable to future changes in transportation technologies.

The broadest measurement of our economy is produced by aggregating the value of all goods and services including transportation. This method of measurement appears to be the best alternative. Indeed, value is the only means recognized as measuring productivity output in a service industry such as transportation. The U.S. Bureau of Labor Statistics (15) states:

> Output refers to the finished product or the amount of the product added in the various enterprises, industries, sectors, or the economy as a whole. Output is measured for industries producing not only goods, but also services that are difficult to quantify. . . .Further, when information on the amount of units produced is not available, as is often the case, output must be expressed in terms of the dollar value of production, adjusted for price changes.

As a result, the prices paid for transportation reflect the value of the service as perceived by the shipper. In other words, because transportation does not produce goods, modes cannot be compared by physical measurement. They can and should be compared by their dollar value of production, i.e., gross freight revenue or expenditure.

If this method is used, freight transportation analysis can focus on the value of service supplied and the value-determining physical attributes of that service. Consider Nelson's statement (16) in discussing trucking operations:

> The dollar value of service (freight revenue) provides a common measure of trucking output which may be used when comparing and analyzing the output of different carriers in any

Table 1. Ton-miles and value of transportation by mode of transport.

Mode	Ton-Miles (millions)	Percent	Value (millions of dollars)	Percent
Air	3,800	0.2	770	1.3
Pipeline	468,000	20.1	1,300	2.2
Rail	781,000	33.6	13,500	22.8
Truck	470,000	20.2	41,668	70.4
Water	603,000	25.9	1,982	3.3
Total	2,325,800	100.0	59,220	100.0

Note: 1 ton-mile = 0.56 Mg·km.

Table 2. Ton-miles, value of transportation, value of shipment, and value added by mode of transport.

Mode	Ton-Miles (millions)	Percent	Value of Transportation Expenditures (millions of dollars)	Percent	Value of Shipment (millions)	Percent	Value Added (dollars)	Percent
Rail	731,000	41.4	10,148	24.1	156,673	32.0	68,581	30.6
Truck	389,000	22.0	28,930	68.7	297,211	60.7	141,644	63.3
Other[a]	645,000	36.6	3,020	7.2	35,342	7.3[b]	13,602	6.1[b]
Total	1,765,000	100.0	42,098	100.0	489,226	100.0	223,827	100.0

Note: 1 ton-mile = 0.56 Mg·km.

[a]Oil pipelines (regulated and nonregulated), inland waterways (including the Great Lakes, but excluding international, coastal, and intercoastal), and airways.

[b]Excludes pipelines.

single year. Adjusted for price level changes, revenues also provide the means for describing changes in the output of the same carrier or group of carriers from one year to the next.

Such analysis is readily adaptable in discussions of not only intramodal but also intermodal transportation. Table 1 gives the relationship of ton-miles (a physical measurement) to value (a monetary measurement). (The data in the table are from 1972.)

Although railroads carried 33.6 percent of the total ton-miles, the value of these ton-miles as reflected in the total amount of money spent for them was only 22.8 percent of the total spent for all freight transportation. Air carriers, on the other hand, handled only a small fraction (0.2 percent) of the ton-miles but spent 1.3 percent of the money. The value of truck service represented 70.4 percent of the total transportation dollar spent for all intercity transportation but accounted for only 20.2 percent of the ton-miles.

Another approach that might be taken is to consider the value of the goods moved as an indicator of the economic importance of transportation. This is given in Table 2. Note that, although trucks move fewer ton-miles, they carry items that are high in value. Shippers of these goods with higher values demand and can afford to pay more for the better service that trucks provide. Regrettably, the latest data for value of shipments are for 1967. However, when the 1972 data are made available, they will almost surely show that trucks moved even greater portions of high-value shipments.

Another measurement of transportation output that might be used is value added. As applied to manufacturing, value added is defined as follows (16):

> The difference between the value of goods and the cost of materials or supplies that are used in producing them. Value added is derived by subtracting the cost of raw materials, parts, supplies, fuel, goods purchased for resale, electric energy and contract work from the value of shipments. It is the best money gauge of the relative economic importance of a manufac-

turing industry because it measures that industry's contribution to the economy rather than its gross sales.

The value added for manufactured goods handled by each mode is also given in Table 2. This is computed by multiplying the percentage share of tons handled by each mode by the dollar value added by production, measured at the three-digit level of the standard industrial classification (SIC).

Unfortunately, value added can be measured currently only for manufactured goods. Services, including transportation, do not readily lend themselves to this type of analysis because they do not produce a physically measurable unit. Transportation's role merely reflects the percentage share of tons handled in relation to the value added produced by those tons. If data could be developed to determine specifically the value added by transportation, the measurement of transportation output would be greatly enhanced. Value added by Transportation could be applied intermodally as well as intramodally. Tying transportation to the national economy by using value added instead of measuring operating expenditures would be a refinement over other methods because the sum of all value added levels would equal, by definition, gross national product.

CONCLUSION

U.S. transportation policies have been hampered for too long by faulty analyses based on the inappropriate use of ton-miles (megagram-kilometers). The types of fallacious conclusions being drawn from such analyses must be exposed. More important, a realistic method or methods of measuring transportation that will permit meaningful comparisons of different kinds of transportation outputs must be developed. The need is urgent. We, therefore, urge that the Transportation Research Board address this problem on a priority basis and that it appoint a committee or subcommittee representative of government agencies, carrier representatives, and transportation engineers and economists to study this problem.

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