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Allocating the Costs of Railroad Infrastructure to Specific Traffic Classes

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Introduction

More efficient transportation systems promote economic growth and inter-regional trade. While no doubt true, this statement is too qualitative to be of much use to planners, government officials, or anyone else. Considerable effort is required to quantify these relationships. Network models can predict how traffic flows will adjust to changes in transportation costs or network configuration for particular regions or modes. More general equilibrium models can predict how population and economic activity will shift in response to changes in the transport system. These models provide a useful theoretical framework for examining public policy, especially public investment in transportation infrastructure. Advances in theory, computers, and technique now allow economists to apply "Computable General Equilibrium Models (CGEM)" to illustrate the local and regional effects of major investments (Bröcker, 2000). The term "computable" is used to emphasize the fact that these are not mere theoretical constructs, but models that can actually be calibrated using available data to address policy issues of current interest.

How well these models capture the essence of transportation capabilities depends in part upon your perspective. From an economist's perspective, these network models are quite complex, using highly detailed, mode-specific costs for each link in extensive transport networks connecting dozens or hundreds of regions. Transportation economists would likely prefer to use a much simpler econometric model that would provide insight into trends in costs or demand elasticities. However, engineers would consider the network models to be quite general, as they
use quite aggregate measures of transport costs and it is often unclear how they treat technology. Carrier officials would probably find network models to be far too abstract for evaluating specific investment decisions; they might be perfectly happy using "rules of thumb" to estimate costs or they might analyze investment options taking into account nuances related to technology and the timing of investments. The matter of perspective is not necessarily that critical, however, as a modelling approach can be quite effective even it is not inherently useful to everyone.

A more serious concern is whether the modelling approach stands up to scrutiny. Are the assumptions used in the model appropriate for investigating the issues that are addressed? Engineers, economists, and managers might be interested in different levels of aggregation and different portions of the system, but - if they had the time and the inclination - they should all be able to address the assumptions and methodologies that would be appropriate for different types of analysis. Even though engineers or managers might not normally use a CGE model, they could assess the way that the model represents transportation costs and investment opportunities. They might even agree that a comparison of long-run marginal costs by mode should be used a) as a general guide for developing public policy and b) as the key to flowing traffic over a network in a specific study. And they might agree that these costs can be expressed as the cost per ton-km of shipping a particular commodity by a particular mode over a particular route.

Disagreements begin when particular costs are assumed for particular modes. Average costs are sometimes used to compare rail and truck, without taking care to distinguish among different types of service (e.g. unit train vs. boxcar or less-than-truckload vs. truckload). Even if costs are broken out properly by the type of service, the costs may not reflect enough of the characteristics of a particular trip to be realistic. For example, the average cost per ton-km can be obtained by dividing total costs by total ton-km and applying the result to all movements or by using a simple cost function:

\[
\text{Total cost/ton = } a + b*(\text{kilometers})
\]

\[
\text{Cost/ton-km = (a/kilometers) + b}
\]

This simple equation at least corrects for the distance of the shipment and allows better differentiation between a boxcar shipment where there is a high fixed cost and a truckload shipment where the fixed cost might be quite small. However, a more extensive cost function will be needed to capture enough of the characteristics of a shipment so that the manager or the engineer will be reasonably comfortable with the ultimate estimate for the cost/ton-km for a particular shipment. For a good example of a very detailed, engineering-based cost function that
is presented within a solid economic framework, see the transport model that Roberts developed for looking at transportation investment options in Colombia (Kresge and Roberts, 1971).

There is also the question of what costs are being allocated and why they are being allocated. In pricing, two factors dominate: the demand for the service and the marginal cost of producing the service. If price exceeds marginal cost, then there is a contribution to overhead and profit and the price is reasonable. Fully allocated costs are not relevant to specific pricing decisions. However, as Locklin points out, "even though fully allocated costs are usually of little significance in fixing rates, it is sometimes desirable to know what such costs are. When a particular kind of traffic can bear its full proportion of fixed or overhead costs, there is no reason why it should not do so" (Locklin, 1966, p. 153). Much of the economic discussion of rail rate regulation concerned the extent to which rail costs varied with traffic volume. When traffic densities were low, half to two-thirds of costs may well have been fixed, but Locklin, writing in the middle of the 20th century believed that 70-75% of long-run rail costs vary with traffic, except on light density lines. At the start of the 21st century, with much higher traffic densities, it is clear that most rail costs are variable and that most can be traced to the engineering and operating characteristics associated with particular traffic.

There is an extensive literature on railroad costing; Wilson (1980), Button and Pitfield (1985), and Braeutigam (1999) provide numerous references to the regulatory and econometric literature. Manheim (1979) provides a systems analysis framework for looking at transportation costs, taking technology and operations into account in developing cost functions similar to those that Roberts used in Colombia. Over the past 20 years, there have been many costing studies and analyses of railroad costs from an engineering perspectives, but Manheim's statement remains true: "the literature of [transportation] technology is vast, but seminal material is sparse" (Manheim, 1979, p. 207). Much of the best railroad cost analysis has been done by consultants and researchers working for individual railroads, creating a body of work on technology, productivity and cost that delves into great detail on many railroad topics. This work has been published as reports to governments or to agencies on specific topics, often with well-developed cost and production functions and thorough appraisals of the effects of new technology or new operating practices (e.g. Smith, 1990).

**INFRASTRUCTURE COSTS**

There are several distinct components of infrastructure costs that complicate cost allocation for railways. In general, costs could include some or all of the following costs, some of which may
be overlapping:

- Costs of constructing or upgrading track and structures
  - Base costs of providing a single rail line
  - Added costs of providing capacity for bi-directional operations
    - Sidings and multi-track segments
    - Signaling
  - Added costs for allowing faster operations
  - Added costs for allowing heavier equipment
- Maintenance expenses for track and structures
  - Routine inspection and maintenance that must be done on a regular basis if there is any traffic at all (e.g. bolt tightening, defect repairs, and weed control)
  - Periodic tie replacement and surfacing in order to maintain track strength and geometry within safe limits
  - Periodic replacement of track components as a result of wear and fatigue
- Depreciation of track and structures
  - Increase in the net present value (NPV) of future track maintenance expense
  - Reductions in the value of the facility because of deterioration in its condition
- Costs related to capacity limits
  - Opportunity costs of train delays associated with meets and passes and maintenance activities
    - Increased cycle time for rail equipment
    - Longer, less reliable trip times, which will increase customers' logistics cost and reduce demand
  - Opportunity cost of lost contribution from traffic that could not be handled because of physical capacity constraints

Cost allocation could involve any or all of these cost elements. Light density branch lines represent one extreme case, where routine inspection and maintenance dominate. High density lines with mixed freight and passenger service represent the opposite extreme, where each type of cost is likely to be relevant.

For low density operation on existing branch lines, neither capacity nor service is an issue, as a few trains a week can easily move all the traffic, and it matters little whether they operate at 5 or 50 mph. These lines were likely constructed more than a hundred years ago, and the original costs of land acquisition, grading, bridges are sunk costs long forgotten by all concerned. The railroad can likely continue a low level of operations with modest expenditures to ensure a
minimum level of track support and acceptable track geometry for slow speed operations. The value of the branchline will be based upon the overall profitability of the traffic originating and terminating on the line. So long as the contribution to overhead and profit exceeds the costs of maintenance and operation on the line, it makes sense to keep the line open (assuming there are no higher uses for the right-of-way). So long as no major work is needed for ties or surfacing or bridges, the line can continue indefinitely, even with very old rail.

For high density lines, capacity is a problem. With commuter operations, there will be a "rush hour" phenomena, just as in highway systems. For freight, operating 24 hours a day, 7 days a week, there may be seasons where high traffic volumes lead to congestion that persists for weeks or months. In either case, there could be two kinds of capacity cost for an additional train: an increase in total train delay or the opportunity cost of not operating a different train. As in highway rush hours, the incremental delay will be much higher than the average delay, as an added train will increase delays for all trains. For freight, there will eventually be a physical limit to the number of trains that can be handled on a line; once this limit is approached, then the railroad will perceive an opportunity cost as any added train will be using a slot that could have been used by another, possibly more profitable train. As the physical capacity is approached, the owner of the infrastructure will consider adding capacity or rationing demand (by increasing prices, by selective marketing, or by rationing slots).

In North America, capacity costs were largely irrelevant for a 40-year period following the widespread introduction of the diesel-electric locomotive in the 1950s. With this technology, it was easier to operate longer trains, which increased line capacity. The introduction of the 100-ton car in the 1960s and the diversion of much general merchandise traffic to truck or intermodal in the 1970s further reduced the demand on the infrastructure as measured by train-miles. It was not until the 1990s that train-miles began to rise to the levels of the 1950s. With rising traffic and a rationalized infrastructure, the rail industry no longer has a problem with excess capacity. Quite the reverse is true. With recent examples of prolonged congestion throughout the US and Canada, it is again important to consider the costs of capacity and the opportunity costs of using limited capacity for traffic that is at best marginally profitable.

The physical requirements can be quite distinct for different traffic classes. In general, passenger traffic requires better track geometry (for passenger comfort and higher speed operation), higher superelevation (for higher speed operation around curves), and more expensive turnouts (to minimize passenger discomfort when crossing the switch points). Freight operation requires more durable track components, but generally can tolerate slower speeds and poorer ride quality in order to obtain lower costs. Within freight, some traffic (e.g. intermodal and automobiles)
requires smoother operations and higher speed, while other traffic (e.g. coal and grain) requires components and structures that support heavy axle load operations.

In the following sections, we will look at some of the techniques that have been developed to deal with these issues. We will also provide some examples, using typical costs to illustrate why certain types of issues become paramount in allocating track costs in various situations.

**ALLOCATING TRACK EXPENSE USING SERVICE UNIT COSTING**

Regulatory commissions have developed or accepted elaborate cost functions for use in setting or approving price structures. In the US, the so-called "Form A" cost structure was used for many years by the Interstate Commerce Commission in railroad rate cases. Form A builds upon an accounting system; all expenses for a railroad are divided into various categories, each of which varies with a specified "service unit" such as ton-km, loaded car-km, or tons. With service-unit costing, costs are estimated by a three-step process:

1. The cost per service unit is estimated for each expense category (this can be a simple average or, preferably, this can be based upon a regression taking into account such things as the size of the railroad).
2. The number of service units is estimated for a particular shipment, using actual or average shipment characteristics (e.g. the equation could be based upon actual tonnage or the average tons/load for the commodity in question).
3. The cost per shipment is estimated by summing the costs associated with each service unit.

This or a similar approach is commonly used in carrier costing systems as well as in regulatory situations. Expenses related to track and structures are commonly related to gross-ton-miles, sometimes with empirical factors that purport to account for the differences in passenger and freight ton-miles. Economists have long pointed out problems with this approach, notably that the relationships between costs and service units may be more complex than the linear relationships that are often assumed. Nevertheless, this is a straightforward method that is easily adopted by a carrier or a regulatory commission - or anyone else who has access to the accounting and operating data.

Service unit costing works best when traffic, operations, and technology are stable and past relationships can be expected to continue into the future. Service unit costing is more difficult when traffic flows, operations or technology are expected to change significantly over time,
causing changes in the relationships between costs and service units. Service unit costing is also most appropriate when expenses are readily identified and easily allocated to particular traffic classes. Costing becomes more difficult when there are joint expenses for two or more traffic classes (e.g. freight and passenger trains using the same tracks) or where costs do not necessarily show up as expenses (e.g. physical deterioration of infrastructure). We will look at this problem in some detail in the rest of this paper.

**THE IMPORTANCE OF RAILWAY INFRASTRUCTURE COSTS**

Railway track and structures account for 10-50% (or more) of railway operating costs, depending upon the characteristics of the route. On low density lines, inspections and routine maintenance are major cost concerns; on high density lines, capital requirements dominate, especially rail replacement, and infrastructure costs will be a smaller proportion of total costs. On all lines, the quality of the infrastructure determines speed limits as well as the size and weight limits for freight cars and trains. With better track materials and stronger bridges, it is possible to run longer, heavier, and faster trains, thereby improving operating productivity. Hence there is a fundamental tradeoff regarding investment in track structure and the variable costs of rail operations.

This tradeoff can be quite important in the types of issues that might be addressed by CGE Models, as these models frequently are considering major investments in new routes or in upgrading existing routes. The nature of the investment will determine not just the capital and maintenance costs associated with the infrastructure, but also the operating possibilities - and therefore the variable operating costs that will be achievable over the new system. It is therefore important to make sure that the assumptions about operating costs are in fact consistent with the assumptions about infrastructure! The next section will present a methodology for considering track costs; a similar approach can be used for bridges.

**MODELLING RAILWAY TRACK COSTS**

Beginning in the mid-1980s, the Association of American Railroads sponsored a series of research projects aimed at understanding how life cycle costs are based upon underlying engineering relationships, namely the deterioration of track components under load. This research led to the development of a model - actually a set of related models - called TRACS for the “Total Right-of-Way Analysis and Costing System” (Hargrove and Martland, 1991; Martland, 1993; Auzmendi, 1994). The research was initially motivated by a desire to use more
realistic cost functions in regulatory proceedings concerning rates for unit coal trains. The idea was that engineering-based models would be able to show the incremental costs associated with incremental traffic. The models were also intended to be useful in technology assessment, predicting the changes in track costs that would be associated with the use of better components or new types of cars or locomotives. Over time, the model was used extensively in evaluating the economics of increasing axle loads.

TRACS has separate modules for each of the major track components: rail, turnouts, ties, and ballast & subgrade. Track expenses are incurred for inspection, routine maintenance, and component replacement. There are several dozen specific activities that are considered in the model, and the predicted track cost is based upon the frequency of and the unit costs for these activities. Eventually, the condition of the track deteriorates to the extent that major rehabilitation is required.

For rail, the major activities are ultrasonic inspection (to find internal defects), replacing rails with internal defects, joint maintenance, lubrication, grinding, and rail replacement. Ultrasonic inspection is done several times per year, with the frequency increasing as the traffic volume or the expected number of defects increases. Routine, visual inspections are much more frequent. When bad joints, broken rails, or defects are found, they are repaired. Grinding may be needed periodically to maintain the proper geometry and a smooth running surface on the rail; grinding also helps to control the number of defects. Lubrication helps reduce rail wear on curves. Over time, it will become necessary to replace the rail because of excessive defects or excessive wear. With good rail and maintenance practices, defects are seldom the limiting factor for rail life for modern mainline operations. Instead, grinding and the passage of millions of tons of traffic eventually wear away a significant portion of the rail head and it will be necessary to replace the rail. However, in situations where there is a marked increase in annual traffic volume or in axle loads, rail defects can be the reason for replacing rail. Defect rates are roughly proportional to total traffic volume and increase more than linearly with axle loads, so defects can be a problem on heavy haul freight lines. Defect limits are commonly stated in terms of the number of defects per mile of track per year, rather than defects per million gross tons of traffic (MGT). This means that lower density lines can tolerate a higher defect rate per MGT than will be acceptable on high density lines. Hence, it is possible to remove rail from a high density line where it has reached a defect limit and relay it on a light density line where it will last for many years before reaching a wear limit!

The life of the rail therefore depends upon the following factors:
• The forces exerted on the rail, which depend upon the type of equipment, axle loads, track curvature, and train speed
• Wear rates and defect rates, which depend upon the quality of the rail, effectiveness of lubrication, and the forces exerted on the rail
• The amount of grinding that is required, which also depends upon the quality of the rail and the forces
• The quality of lubrication
• Wear limits (amount of head loss that is acceptable) and defect limits (the maximum number of defects per year per mile of track)

In TRACS, results from engineering models are used to estimate the forces exerted on the rail by each type of car; results from field measurements are used to calibrate the wear and defect models for the commonly used types of rail steel (Clark et al., 1999). Grinding and lubrication levels and wear and defect limits are based upon standard industry practice. The model deals with one track segment at a time, simulating the yearly deterioration of the rail as different traffic classes move over the rail. If the cumulative wear or the annual number of defects exceeds a limit, then the rail is replaced. The model keeps track of the annual maintenance activities and records the expected time when the rail will be replaced.

Allocating rail costs to traffic classes depends upon the reasons that rail is ultimately replaced. For typical North American freight operations, rail wear rates are proportional to MGT, independent of axle loads. If wear is the dominant reason for rail replacement, then it makes sense to allocate rail replacement costs to traffic classes in proportion to the total gross tonnage in each traffic class. If fatigue is the dominant reason for rail replacement, then cost allocation is more complicated. The fatigue life is the cumulative MGT for which the defects per mile per year is expected to exceed a specified limit. The fatigue life depends upon the hardness and cleanliness of the steel and the axle loads of the traffic. For some of the older rail still in service in North America, the fatigue life might be 2000 MGT for general merchandise traffic moving in boxcars, but only 400 MGT for coal traffic moving in heavy cars. Hence, if fatigue is the reason for replacing this rail, costs must be allocated in such a way as to reflect the effect of each traffic class on fatigue. TRACS handles this by calculating the expected percentage of the fatigue life that is consumed each year by each traffic class. In the above example, 20 MGT of merchandise traffic would consume 1% of the fatigue life of the rail, but 20 MGT of coal traffic would consume 5% of the life of the rail. If this was the only traffic on the line, then the coal would be allocated 5/6 of the costs related to rail replacement.

TRACS conducts similar analyses for turnouts, ties, and ballast & subgrade. The nature of the
forces, the maintenance activities, and level of detail in the engineering calculations vary within the modules, but all have the same general structure as the rail model. The forces on the components depend upon the nature of the equipment, the route, and the type of component; the ability of the components to withstand the forces depends primarily upon the quality of the materials. The model estimates the activities required each year over the time horizon of the analysis and determines when major rehabilitation is needed.

Each maintenance activity has an associated unit cost, which can be a typical cost (e.g. $250,000 to replace one mile of rail, using standard rail) or a cost that is calculated as a function of wage rates, crew size, equipment costs, and productivity (e.g. $20 per hour for each person of a 50-person rail gang that uses equipment costing $10,000 per day to relay standard rail that cost $600/ton, ...).

Given the unit costs and the timing of all the maintenance and capital activities, it is possible to estimate the total track costs for each year. Using an appropriate discount rate, this set of cash flows can be converted to a net present value or to an equivalent uniform annual cost (EUAC). If traffic is stable, the cost per gross- or net-ton-km can be estimated by dividing the EUAC by the annual gross or net tonnage.

This is a very flexible approach to costing, as it is possible to change the traffic, the technology, the route structure, or the unit costs. To estimate the incremental costs for a traffic class, it is only necessary to compare to compare two sets of results: one set for a base case and one for a case with the incremental traffic. Adding a small increment of, say, two million gross tons of traffic will increase the frequency of some routine maintenance activities (e.g. rail grinding), cause a slight increase in others (e.g. rail defects per year), and move rail replacements and other major capital project forward a few months. This calculation can be done for each traffic class in turn, treating each one as if it were the last increment of traffic, in order to get an equivalent incremental cost for each traffic class. The total cost could then be apportioned based upon the ratios of these incremental costs.

**Effect of Traffic Density and Axle Load on Track Costs**

There are strong economies of density in track costs. Exhibit 1 shows the EUAC for track costs for lines varying from 3.3 to 90 MGT (million gross tons/year). This chart is from a study of the costs of operating unit coal trains over a network similar to what serves the Powder River Basin in Wyoming in the western US (Chapman *et al.*, 1997b).
Chapman used TRACS to estimate steady state costs for routes representing the lines serving the mines, the major coal routes, and the lines serving the power plants that received the coal. For each segment, he used track and route characteristics appropriate for the assumed level of tonnage. The highest density line had 60 MGT of coal traffic plus 30 MGT of general freight and intermodal traffic. The lowest density line was a 3.3 MGT line serving an individual power plant. It is evident in this exhibit that tie costs are fairly constant for all of the segments, rising only by a factor of 2 when annual tonnage rises by a factor of 30. Ties deteriorate primarily from biological factors that are unrelated to tonnage; hence tie costs are a major component of track costs for low density lines but a fairly minor problem for high density lines. Rail is the opposite: a minor cost for light density lines (once it is installed!) but the largest cost for the higher density lines. Exhibit 2 shows the EUAC/gross-ton-mile and net-ton-mile for the same lines. Costs are clearly declining as the line density increases. In this example, costs are proportional to MGT$^{0.63}$.

Increasing axle loads is an important issues in North America and in heavy haul freight operations around the world. With heavier axle loads, it is possible to carry more freight in each car, which provides economies in car ownership costs and in train operations. Exhibit 3 shows how the track costs for the western coal lines are expected to increase as the axle load is
increased from 33- to 39-tons. Rail fatigue, turnouts, and bridges are the main problems as axle loads increase. Cleaner, harder rail steel can be used to deal with the rail fatigue problem; harder steel and improved designs can strengthen turnouts. Overall, track costs increase approximately linearly with axle load, although the actual percentages vary with the traffic density, traffic mix, and quality of the track structure.

Bridges, whose costs are not included in these exhibits, are the major long-term problem, as major rehabilitation or replacement may be necessary for some important structures. Needless to say, bridge costs are highly dependent upon local conditions. It is possible that it would be necessary to replace a major bridge in order to allow higher axle loads, which could add $20 million or more to the initial cost of increasing axle loads.

TRACS is a performance model, not a supply model. It estimates component lives and track costs once the user specifies the track structure, maintenance policies, traffic volumes, and unit costs. It does not attempt to optimize the track components for a particular traffic mix, let alone try to develop a long-term cost function for track. In principle, however, this approach could be used repeatedly with many combinations of inputs to find the optimal track structure for a particular situation or to develop a long-run cost function covering any traffic mix or traffic volume. This long-run cost function would give the track cost for the best combination of components and maintenance policies for serving particular traffic given specific component costs. Because of the long-lives of rail components, it is unclear how useful such a function would be even if it were available. In practice, such analysis would be done only when a new line is to be built or when significant investments are being considered for existing lines. Distinct infrastructures have evolved for high speed rail, heavy haul rail, and commuter rail operations; the engineers working with systems are - as a group, if not individually - well aware of the costs and operating consequences of various options for upgrading the track structure.
ROUTE CAPACITY

Line capacity is another input to a network model that requires some consideration of the underlying engineering issues. In general track capacity can be matched to traffic density by varying some combination of the following aspects of the operation and the infrastructure:

1. The length and spacing of passing sidings (longer sidings allow longer trains; more closely spaced sidings allow more trains per day)
2. Operating speed (dependent upon track and route geometry as well as control capabilities)
3. The time required for track maintenance (much lower with better inspection, better components, and automated maintenance equipment)
4. Signal block length (shorter blocks allow trains to travel closer together, which increases the capacity of multi-track operations and reduces recovery time after maintenance or other delays in single track operations)
5. Terminal capacity for receiving and originating trains (similar to the gate problem for airports: if there isn't a track available, the train must wait out on the line)

In general, higher density operations justify the use of better technology. For very high density operations, it is essential to use the best technology in order to minimize train delays.

These capacity relationships, like the engineering relationships, are all quantifiable. For example, Dontula (1991) used a simple simulation model to estimate the relationship between siding spacing and line capacity for a single track line. The results for a 100-mile line segment are shown in Table 1. Here, trains are assumed to operate at 45 mph, departing at regular intervals from each end of the line. Capacity is determined as the maximum number of trains that can be dispatched per day without encountering excessive delays. The sidings are each 2 miles long, and the length of the single track segments between sidings is shown in the table. This table shows that going from 2 to 6 sidings increases the total miles of track by only 8%, but quadruples the capacity of the line. Over most of this range, adding a siding increases capacity by about 10 trains/day. If the cost of construction is assumed to be $1 million per siding, then the initial cost of increasing capacity by one train/day is on the order of $100,000. Ultimately, however, adding more sidings does little to help capacity because of the fixed delays associated with train meets, even for very short single track segments.

Table 1 Increasing Capacity by Adding Sidings
(Source: Dontula, Figure 5.3)
For a single track line with a fixed number of siding, train delay increases with traffic volume. Table 2 shows some more simulation results from Dontula, who varied the number of trains from 6 to 48 per day for a 100-mile line with 8 sidings. In general, as more trains are added, average delays go up. The table also shows that the increment total delay increases dramatically as train volume reaches the maximum that the line can handle. Using Dontula's results, I have estimated annual train delay costs for two extreme cases:

- Unit coal trains - the delay cost is estimated to be $250/hour, which is the approximate hourly ownership cost for the locomotives and freight cars in a typical 100-car train
- Passenger trains - the delay cost is estimated to be $5,000/hour, which assumes 500 people on the train with an average value of time of $10/hour

The table shows that adding a train to this route adds about 1-2 hours to total meet delays each day. Over the course of a year, this is a cost of $100-200,000 of delay cost for each additional train on a freight line and $2.5 - 3.5 million for each additional train on a passenger line. These delay costs might seem quite enough to justify the one-time costs of adding a siding, which was estimated to be on the order of $1-2 million and increase capacity by at least several trains a day.

### Table 2: Incremental Delays and Delay Costs for a Hypothetical Single Track Rail Line
(Source: train delay from Dontula, Figure 5.2)

<table>
<thead>
<tr>
<th>Trains/day</th>
<th>24</th>
<th>30</th>
<th>36</th>
<th>42</th>
<th>48</th>
<th>54</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average delay (min/train)</td>
<td>6</td>
<td>24</td>
<td>20</td>
<td>28</td>
<td>40</td>
<td>46</td>
</tr>
<tr>
<td>Total delay (hrs/day)</td>
<td>2.4</td>
<td>12</td>
<td>12</td>
<td>19.6</td>
<td>32</td>
<td>41.4</td>
</tr>
<tr>
<td>Incremental delay (hrs/day/train)</td>
<td>1.6</td>
<td>0</td>
<td>1.3</td>
<td>2.1</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Annual incremental delay cost at $250/hr</td>
<td>$0.15</td>
<td>0</td>
<td>$0.12</td>
<td>$0.18</td>
<td>$0.15</td>
<td></td>
</tr>
<tr>
<td>Annual incremental delay cost at $5,000/hr</td>
<td>$2.90</td>
<td>0</td>
<td>$2.40</td>
<td>$3.65</td>
<td>$2.90</td>
<td></td>
</tr>
</tbody>
</table>

On the other hand, track capacity is also affected by the vehicle and train characteristics, and it
may be possible to get additional capacity for freight by running longer heavier trains even if no money is spent to add sidings. The following strategies are employed for freight, and similar schemes are used to increase passenger volume for commuter and intercity trains:

1. Increase vehicle size and weight limits
   a. Loading density is the key (net tons/length of car)
   b. Clearances are critical for some traffic classes (automobile carriers and double-stack container trains require very high clearances)
   c. Maximum axle loads are important when car length is fixed
2. Increase train weight and length limits
3. Change the traffic mix, e.g. reduce the proportion of empties or increase bulk relative to merchandise traffic

Capacity can also be increased by better management practices. Implementing better dispatching systems may allow a 5-10% increase in track utilization. Smoothing peaks in demand may allow a similar or even greater increase, depending upon the pattern of weekly track utilization.

Taking all of these factors together, it is pretty clear that a single track rail line has a great deal of capacity, so that freight railroads will try to run longer, heavier trains, lengthen sidings, and improve maintenance procedures in order to avoid the very expensive option of adding multiple track segments. The differences in train delays costs between passenger and freight trains are quite interesting, since they highlight a key difference between passenger and freight operations: passengers want speed, coal and grain don't care. Double track will be perceived as necessary or desirable for passenger operations long before the same train volume would justify double-tracking a freight line.

**Allocating Capacity Costs**

The nature of rail, and perhaps all, infrastructure is that there are very substantial fixed costs that must be incurred to provide any service. At least one line must be built all the way from A to B if any trains are to serve this market. Once one line is built, capacity can be greatly increased by adding some signals, a few sidings, better components, and sturdier bridges. In allocating costs, it will therefore be critical to consider whether the fixed costs should be allocated to some primary class of traffic or apportioned to all traffic classes. For pricing purposes, a railroad may well consider the true incremental costs of adding another train, as the railroad can decide which traffic is the primary traffic. More often, the allocation of fixed costs will be a matter for
negotiation, either internally or externally. In negotiating trackage rights agreements, there will likely be extended discussions about what traffic is the base traffic and what is the incremental traffic. In modelling operations, it may be easier to apportion fixed costs, but ultimately there may not be any clear, non-controversial assessment of whether any traffic can be treated as primary or incremental. All that the analysis can do is to estimate the various costs that might help to frame the negotiations and limit the magnitude of the disputes.

For example, by using TRACS in conjunction with models of train operations, it would be possible to design the optimal infrastructure for handling specified traffic classes. This analysis would consider both of the issues we have discussed, namely costs related to track deterioration and costs related to capacity. It might not be easy, but it would be possible to estimate the following:

- \( C_1 = C(P_i, I_{pi}) \): infrastructure costs for serving the primary traffic \( P_i \), assuming that the infrastructure \( I_{pi} \) is optimized for \( P_i \)
- \( C_2 = C(\text{Total}, I_{pi}) \): infrastructure costs for the total (primary plus secondary) traffic, assuming that the infrastructure was still optimized for the primary traffic
- \( C_3 = C(\text{Total}, I_t) \): total infrastructure costs for the total traffic, assuming that the infrastructure was optimized for the total traffic

If we were designing a system, then the incremental cost of adding secondary traffic to the primary traffic would be \( C_3 - C_1 \), as we could adjust the infrastructure to handle the total traffic in the optimal manner. If we were adding traffic to an existing system, the incremental cost would be \( C_2 - C_1 \), since the track structure is already in place and presumably optimized for the existing, primary traffic. \( C_2 - C_1 \) would be greater than or equal to \( C_3 - C_1 \), since \( C_3 \) is defined to be the optimal infrastructure for the combined traffic. For example, adding high-speed intermodal traffic to a line formerly used only for slow coal trains will result in a higher allocated cost for the intermodal traffic than if the line could be redesigned and built to optimize the joint operation.

**COST ALLOCATION - REFLECTIONS ON THE STATE OF THE PRACTICE**

Costing for rail operations is well-developed. Issues of cost allocation were debated at great length during the regulatory era, and considerable effort has been devoted to studying the relationships among various elements of rail costs and relevant operating, engineering, and traffic characteristics. Infrastructure costs have always been among the most difficult railway costs to understand; track costs were commonly allocated on the basis of gross ton-miles, in part
reflecting a lack of knowledge about track costs and in part reflecting the rather minor role of track costs in overall costs. Over the past 30 years, however, track costs became more important, as heavier axle loads were introduced and railroads attempted to maximize the productivity on single track railroads. Today, tools for project-level analysis are available and widely used by railroads and consultants. Tools for engineering-based life cycle costing are available and used by industry research groups. Underlying these tools is the conceptual framework described above.

Note that we are really talking about a production function and a long-term cost function for railway track structure. The analysis of heavy axle loads for coal operations is part of a broader effort to find more efficient ways to move coal and other bulk commodities by rail. The industry has adopted aluminum coal cars with higher gross vehicle weight, heavier and more efficient locomotives, and better track components in order to improve the productivity of shipping coal by rail. From the industry perspective, the production function for coal is something to be discovered through R&D and innovation, and the industry is always looking for better ways to move freight.

For the railroads themselves, data is not a problem. They have vast amounts of data concerning all aspects of plant and equipment. When they perceive a problem concerning costs or cost allocation, they can use their data to support many kinds of special studies concerning productivity or technology. The railroads also use benchmarking as a means of understanding performance capabilities, and they often pool their knowledge through groups like the Association of American Railroads (AAR) to identify best practices.

For researchers, data can be a major problem. There is no readily available source of data concerning track component lives under typical types of services. Although such data is often assembled by researchers and consultants, there is no public repository for such information. Hence, development of valid cost and production functions for rail infrastructure is a task that will require cooperation among researchers and railroads.

**Cost Allocation: Three Types of Applications**

There are at least three major applications of cost analysis that may be of interest. For many public policy issues, it is very desirable to understand the cost/ton or the cost/ton-km of transporting different commodities by the various modes assuming current or projected technological capabilities. At this level of analysis, the question is rather broad - are there types of moves where one mode is, or will become, clearly superior? Are there areas where
competition among modes is likely to continue? Can we afford to make the investments necessary to upgrade the performance of our freight system? For questions like these, expert estimates of aggregate costs may be all that is needed, as they will be able to identify where one mode has a clear advantage.

For network modelling, the costs need to be good enough to be applied for particular links throughout what could be a large, complicated network. For this type of model, minor differences in the type of components will not matter much; the cost of operations and the constraints on vehicle size and train length would be more relevant to shipping costs and shippers' mode choice decisions. The costs must show how distance, shipment size, and route density affect costs - but perhaps not much more than this.

For technology assessment, costs need to be specified at enough detail to capture the effect of the technologies being considered. Using a model like TRACS, it is possible to examine the cost savings from using harder steel or longer-lived ties. However, more detailed engineering models and research results will be needed to determine how the deterioration parameters in TRACS should be changed. Very detailed tests may be needed, as new materials can often be justified based upon detailed assessment of efficiency improvements that would have a negligible effect on the public policy issues. For example, a savings of $0.0003/ton-mile will have no effect on mode share - but will justify the use of a new type of tie.

**Implications for ITEM**

In this paper, I have argued that there are ways to estimate and allocate complex infrastructure costs. However, these methods are likely to be too complex and too data-intensive to be used to develop link-level costs for CGE modelling. What is needed are production and cost functions that can be used to represent the performance of typical services over typical routes at a level of detail that would be appropriate for network models. Given the range of public policy issues relating to rail, it would be useful to be able to break out information for typical services:

- Heavy haul freight lines
- High speed passenger service
- Mixed freight and passenger lines
- Light density lines

The techniques illustrated in this paper could be used to develop parametric cost and capacity functions for these types of operations. Ideally, a set of detailed operating and engineering models would be used to estimate parameters for much simpler link and terminal production...
functions and/or cost functions that could be used for network modelling. They likely could be structured in terms of a few dozen parameters that represent current technology and that could be updated as technology advances.

To a large extent, the information for building such models is available and the methodologies are commonly used by researchers and consultants. This paper has shown how some of the most difficult costing issues can be handled, recognizing that cost allocation will often be a matter for negotiation rather than for economics or engineering science. Although techniques and data are available, they are not necessarily easy to use or to adapt. Much more effort would be required to synthesize information so that it can be used more readily in economic and policy research at the level contemplated by ITEM.

References


Bröcker, J. (2000), Assessing spatial economic effects of transport by CGE analysis: state of the art and possible extensions, paper presented to the First International ITEM Workshop, Montreal, Canada.


