MEASURING THE COST OF INCREMENTAL RAILROAD CAPACITY: A GIS APPROACH

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Abstract

Traditionally, assessing the cost of additional railroad capacity has been accomplished through extensive and expensive engineering studies. Consequently, policy-makers have often been forced to render transportation decisions without information that adequately describes incremental railroad capacity costs. To help remedy this deficit, the current analysis combines observed 1995 railroad traffic with Geographic Information System (GIS) infrastructure descriptions, and generic engineering cost estimates to produce a portable system of capacity cost estimation. The first step in the analytical process involved routing observed rail traffic over a national rail network. Next, link-specific traffic volumes were correlated with link attributes in order to assess the ways in which infrastructure variations can be used to accommodate incremental traffic increases. Finally, engineering cost estimates were used to identify the least-cost method providing desired new railroad capacity. The result is an algorithm that can provide incremental capacity costs in any geographic and operating setting with only a minimal amount of setting-specific information.

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1. Introduction

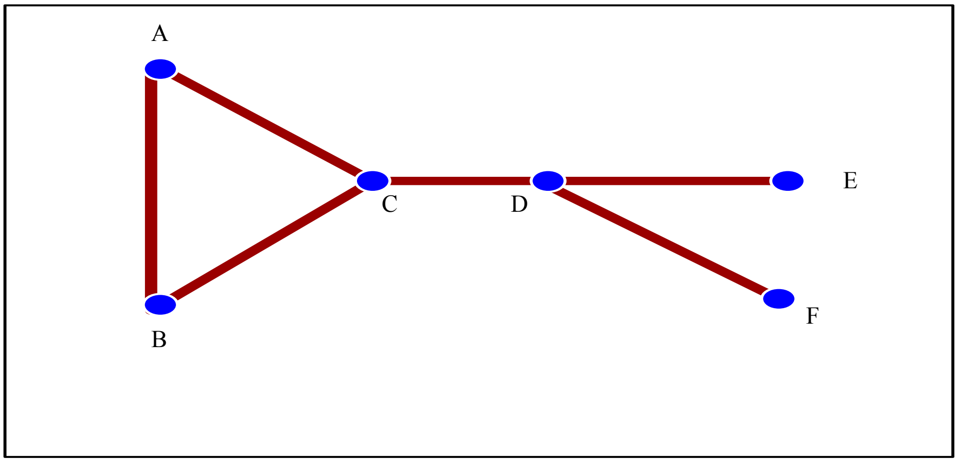
Typically, the costs of incremental increases to railroad line-haul capacity are estimated through engineering studies that fully account for the cite-specific characteristics of affected trackage, as well as the nature of the surrounding physical environment. These studies are both costly and time consuming, so that it is generally impossible to simulate the cost impacts of multiple capacity modifications over an extensive railroad network. The current study seeks to remedy this inability by correlating Geographic Information System (GIS) descriptions of the US railroad network with observed railroad traffic in order to identify the specific route characteristics that facilitate the movement of various traffic volumes. The resulting model makes it possible to identify many combinations of infrastructure improvements that will yield a desired incremental increase in line-haul capacity. Finally, based on generic engineering estimates of track improvement costs, analysts can isolate the least-cost combination of track modifications that will yield the desired new capacity. Section 2 provides a general discussion of railroad line-haul capacity and capacity costs. The model, data, and estimation process are described in Section 3. Section 4 extends the estimation results to include incremental capacity costs and provides an application of the resulting methodology within the upper mid-west. Finally, Section 5 contains some concluding thoughts.

2. Railroad Line-Haul Capacity

Capacity issues must be investigated by fully disaggregating the rail network and evaluating the capacity of each of the links that, together, form specific routes. Both the need for and the complexity of this “link-specific” analysis is made clear through a simple example. Figure 1 portrays a simple network comprised of six nodes (A, B, C, . . .) and six links (AB, AC, BC, . . .). Together, these links form no less than 24 distinct two-way routings. Traffic along such a network could readily move from A to B, from B to F, or from C to E. There are, in fact 15 distinct origin destination pairs that are served by this network. Moreover, in nine cases, there is more than one way to connect a particular pair of points. For example, it is possible to route from A to D by simply going from A to C to D. Alternatively the AC link may be avoided by a routing from A to B to C to D.

It is not sufficient, however, to confine the analysis to individual routes. Even a cursory examination of the network pictured in Figure 1 indicates that a number (15) of the specific routes utilize the CD link. Thus, it is impossible to evaluate the capacity necessary over the CD link simply by measuring the traffic that moves from C to D or from D to C. It is also necessary to consider the need to move traffic from B to E, from A to F, etc. Thus, an accurate evaluation of U.S. rail capacity requires an examination of tens of thousands of potential routings over several thousand individual rail network links.[1]

Figure 1



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[1] In fact the consideration of *every* possible routing over *every* possible link would generate millions and millions of distinct routes. The current analysis, however, restricts the potential number of routings to include only those routes over which traffic is observed. Thus, shipments from Cincinnati to New Orleans via Omaha are generally excluded from consideration.

The concept of link capacity encompasses both space and time. Specifically, link capacity is measured by counting the number of output units (freight cars, revenue tons, etc.) that can be moved over the network link in a specific time period (cars-per-day, tons-per-year, etc.).[2] The actual long-run ability of a link to accommodate traffic is determined by the characteristics of the traffic that uses the link, the physical characteristics of the link, and the ability of traffic to move on to and off of the link. Within the context of railroad transport, these determinants include (but are, by no means limited to) the direction and commodity mix of traffic, the configuration and quality of line-haul trackage, and the ability of terminal facilities to yard, switch, and dispatch trains.

Differing traffic mixes require significantly different infrastructure configurations. Routes that handle largely one-way traffic obviously require fewer opportunities to meet opposing trains, so that sidings (passing tracks) or multiple main lines play a smaller role in determining capacity. Conversely, the capacity of routes that must accommodate two-way traffic (most routes) and particularly routes that see a diverse mix of traffic is heavily dependent on the number and spacing of sidings and/or availability of multiple main tracks.

Apart from link configuration, the physical characteristics and quality of the trackage depends both on the volume and mix of intended traffic. Routes that serve a high percentage of fast moving intermodal traffic may require super-elevated curves, greater clearances and enhanced track quality for higher speed operations. Routes that primarily see bulk traffic movements may be particularly sensitive to grade. Ultimately, the weight of rail used, the anchoring and ballast system selected, the type and spacing of signals, decisions regarding grading and grade separations are all impacted by the mix of traffic that the trackage must accommodate. The variety of relationships between traffic mix and infrastructure requirements

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[2] Within some contexts, the discussion may focus on the length of time it takes to move a single output unit (carload,

is expansive. Moreover, because the mix of traffic can change significantly over time and because the reconfiguration or modification of infrastructure is both time consuming and costly, the match between traffic mix and link characteristics may be less than pristine.[3]

3. Modeling Line-Haul Capacity

The process for estimating and assessing railroad line-haul capacity is relatively straightforward. As noted above, there are many thousands of distinct route segments that vary considerably both in quality and in utilization. It is these variations that provide the basis for statistical estimation. The whole of the process can be is summarized within three steps –

1) Identify a cross-section of railroad route segments and collect information describing the physical characteristics of those route segments including the current level of traffic.
2) Functionally relate observed traffic levels to route characteristics.
3) Using the estimated relationships and the vector of current input prices to estimate the costs of incremental additions to railroad capacity.

The development of Geographic Information Systems (GIS) technologies and coverages has greatly enhanced researchers' abilities to assemble link-specific transportation data and it is four such coverages that provide the basis for the link characteristics used in this analysis.[4] These data were, in turn, modified to incorporate information gleaned from the U.S. Federal Railroad Administration Grade Crossing Inventory files and from other sources.

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ton, etc.) over a specific link. Analytically, these approaches are identical.

[3] For example, as passenger traffic and routings declined, many railroads reduced the elevation in curves in order to reduce the rail wear associated with the operation of heavier slower-moving trains over track designed to accommodate high-speed passenger trains. However, just as many such projects were completed, the volume of intermodal shipments exploded. Intermodal trains are shorter and faster than the typical line-haul freight train, with characteristics that, in many ways, resemble passenger trains. Consequently, many carriers have found it desirable to reverse course and restore the elevated curves in some routes.

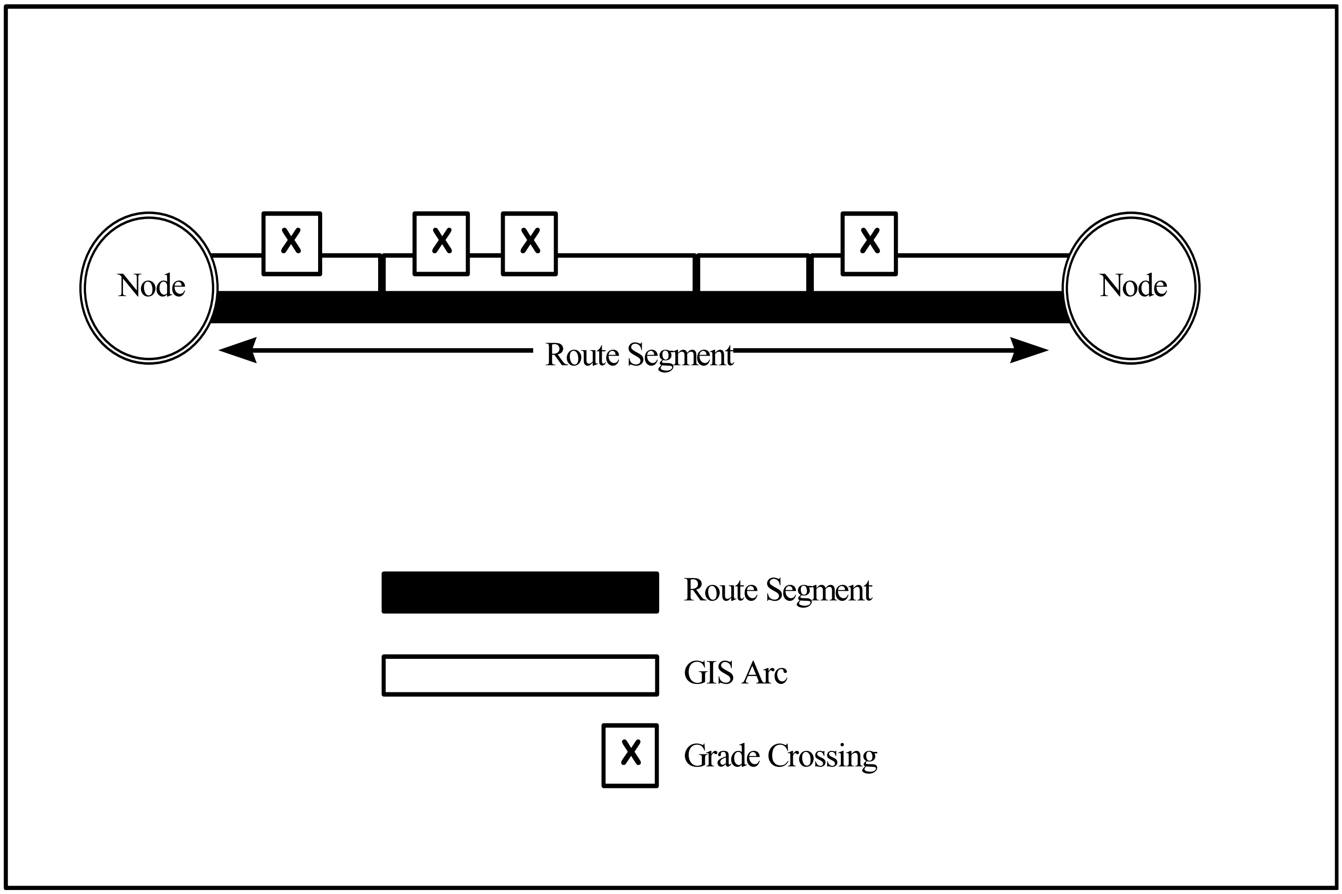
[4] Full documentation of dataset construction, including a description of GIS coverages and manipulations is available upon request.

Initially, a set of roughly 2,500 distinct route segments were defined for use in this analysis. As noted above, a route segment or link for a particular railroad begins and ends at any point where traffic may converge or diverge. Additionally, link end points (or nodes) occur at any location where two railroads may legally interchange traffic. Once the study links were defined, information from four GIS coverages were mapped onto these links. Data from the Bureau of Transportation Statistics' (BTS) 1995 National Transportation Atlas Data (NTAD) 1:100,000 scale railroad network were combined with a newly released Federal Railroad Administration GIS coverage to provide the basic geographic information. These data were combined with data from the BTS 1996 NTAD 1:2,000,000 scale railroad network that contain information describing signaling and a measure of traffic density. The process of developing route characteristics from GIS data is described more fully in Appendix 1. The next step in the data development process involved using a preliminary grade crossing GIS coverage developed by Oak Ridge National Laboratories to locate the position of both separated and grade-level highway crossings. Next, data from the Federal Railroad Administration's Grade Crossing Inventory File were merged with the geographic data in order to provide additional information regarding train speeds, train frequencies and other operating characteristics.

The geographic units, referred to as arcs, are between a few tenths of a mile to several miles in length. However, the shortest route or study segment length is measured in miles and some route segments are several hundred miles in length. Consequently, each route segment generally consists of many arcs. It was, therefore, necessary to aggregate arc level data to conform to the route level unit of measure. This process is depicted in Figure 2. Missing data on some route segments precluded their use in any statistical application. Therefore, the final data set contains roughly 1,400 observations or route segments. The location and extent of their coverage is displayed in Figure 3. A full definition of all route level data used within the final model estimation analysis is contained in Table 1.

At the center of this analysis is a fundamental assumption that the components of the rail network, as configured in 1994-95, were optimally suited to accommodate the traffic moved during that period.[5] Thus, the traffic observed on each link during the study period stands as measure of that link's capacity.

Figure 2



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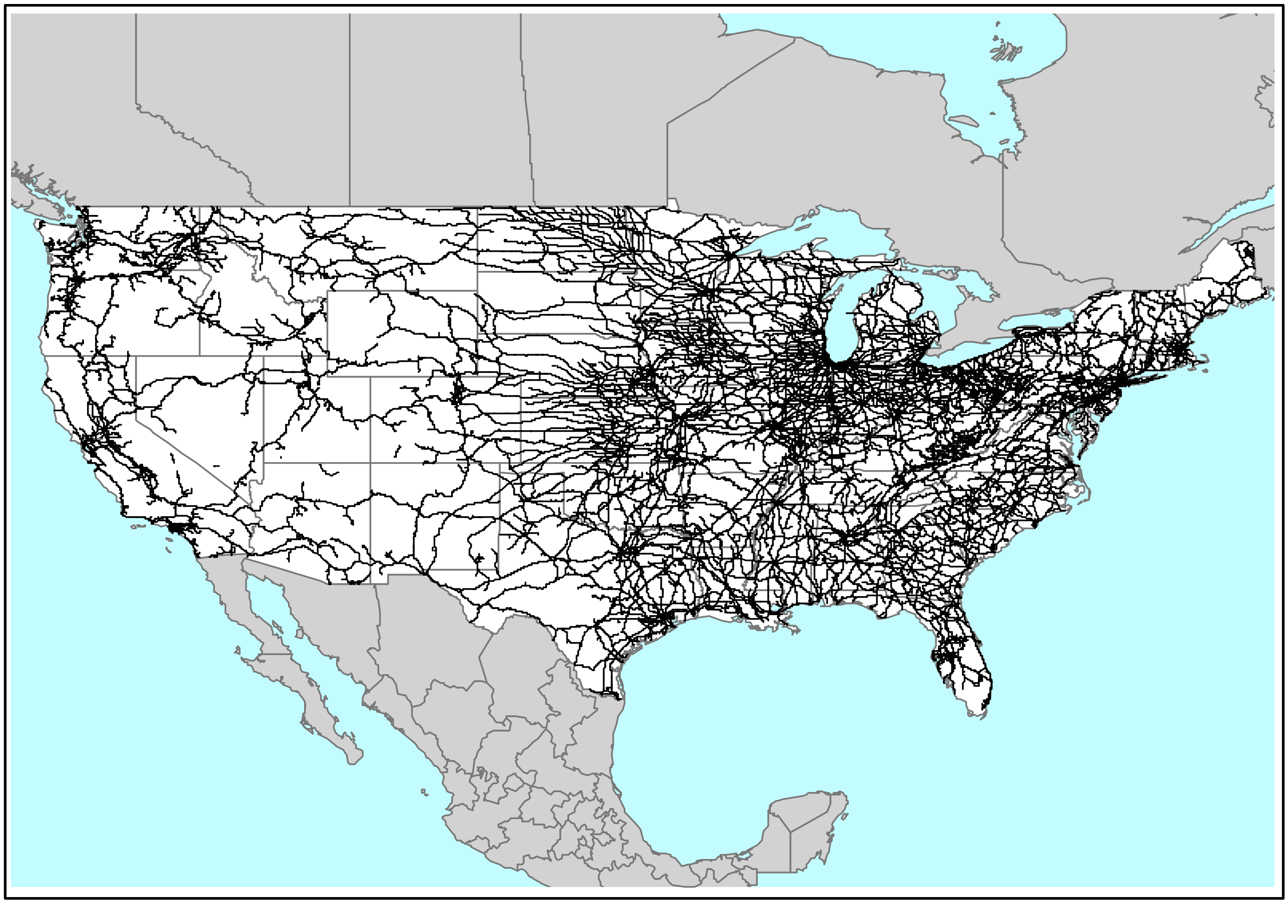
[5]

Figure 3



To measure the traffic over each link, GIS technicians from the Tennessee Valley Authority (TVA) routed the expanded movements from the Surface Transportation Board's annual Carload Waybill Sample over the 1997 FRA 1:100,000 GIS network. A full description of the routing process is available in Appendix 2. However, several points are worth noting here. First, routings were based on actual origin, destination, participating carriers, and recorded points of interchange. Beyond these criteria, routes were selected on the basis of the shortest distance. This "short-line" criteria generally reflects railroad operating practices. This is not, however, true in every case. In order to assess the validity of the algorithm used in the routing process, model outputs for 89 of the 100 hundred most heavily used routes were compared with routings generated by an alternative method.[6] In 80 of the 89 cases, the TVA algorithm generated routes that were virtually identical to the paths generated with the alternative software. In eight cases, there were variations reflecting cases in which railroads opt for a more circuitous routing and in one case, the TVA route varied from the actual routing because of a line sale. The sample of 100 was fully corrected and, because this sample represents between 15% and 20% of all rail traffic, we have complete confidence in a significant portion of the data. Moreover, the remaining rate of error appears to be within acceptable parameters. Once the CWS records were routed over the rail network, tonnage and car loadings were summed at the route link level to form measures of relative capacity

As discussed in Section 2, line-haul link capacity is a function of track configuration and the quality of track components, as well as exogenous factors including, but limited to topography (grade) and weather conditions. A number of model specification and functional forms were discussed with independent transportation consultants and other industry experts. Ultimately, the following model was selected. Variable definitions are provided in Table 1

$$
\begin{aligned}
\mathrm{MAXCARM}_i = \beta_0 + {} & \beta_1(\mathrm{TIMETBLS}_i) + \beta_2(\mathrm{CTCSPEED}_i) + \beta_3(\mathrm{SPEEDRAT}_i) + \\
& \beta_4(\mathrm{TRAINLEN}_i) + \beta_5(\mathrm{MAINS}_i) + \beta_6(\mathrm{CTCMAIN}_i) + \beta_7(\mathrm{SIDSIZ}_i) + \\
& \beta_8(\mathrm{SIDINGS}_i) + \beta_9(\mathrm{SIDINT}_i) + \beta_{10}(\mathrm{ABS}_i) + \beta_{11}(\mathrm{CTC}_i) + \beta_{12}(\mathrm{SWITCH}_i) + \\
& \beta_{13}(\mathrm{SWITCH2}_i) + \beta_{14}(\mathrm{ROUTLEN}_i) + \\
& \beta_{15}(\mathrm{ROUTLN2}_i) + \Sigma\gamma(\mathrm{CD}_i) + \varepsilon_i
\end{aligned}
$$

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[6] The 1995 CWS contains nearly 500,000 records that reflect more than 75,000 routings. Except as noted in the GIS documentation, each of the geographic path of each of these unique routes was calculated for use in this analysis. The comparison routes were developed through the use of PC Rail, a software product produced by ALK Associates in Princeton, New Jersey.

Table 1

Variable	*Description*
MAXCARM	The dependent variable is defined as the natural log of the number of gross carloads accommodated by the i^{th} route link in the busiest 1995 calendar quarter. The log-linear specification was adopted to help capture any non-linear relationships between the dependent variable and explanatory variables. Gross carloads reflect the sum of revenue carloads and estimated empties.[7] The maximum quarterly value was selected to reflect seasonal variations in traffic levels and the assumption that infrastructure is constructed to accommodate the seasonal peak load.
TIMETBLS	Average timetable speed on the route link was calculated by averaging the timetable speed at highway grade crossings. This variable helps capture track component quality.
CTCSPEED	The product of TIMETBLS and CTC, a measure of centralized traffic control described below. This interaction term is included to capture substitutability / complementarities between signal quality and track component quality [8]
SPEEDRAT	The ratio of the minimum train operating speed to timetable speed, included to capture variations in train speeds.
TRAINLEN	The average train length observed along the network link calculated as the gross number of carloads divided by the total number of daily trains.
MAINS	The estimated proportion of mainline tracks within the route estimated by combing the number of mainline tracks at grade crossings throughout the link in question and the carrier-specific ratio of additional mainline miles to total route miles operated.
CTCMAIN	The product of CTC and MAINTRAK. This term is included to reflect substitutability or complementarity between signal quality and the amount of mainline trackage.
SIDSIZ	The average siding length along the route segment.
SIDINGS	Estimated proportion of sidings to mainline trackage based on the carrier specific ratio of sidings to mainline trackage and the number of "other" tracks observed at highway grade crossings along the specific route.
ABS	The percentage of the route link that is controlled by automatic block signals (ABS). ABS is assumed to be inferior to centralized traffic control (CTC), but superior to unsignaled territory.
CTC	The percentage of the route link that is controlled by centralized traffic control (CTC).
SWITCH	The average number of daily switch movements along the link in question.
ROUTLEN	The route length as calculated from the GIS coverage. Because individual arcs were missing from some links, there are numerous instances in which the calculated route length is less than the actual length. This should not, however, affect the validity of the estimation results. To capture in additional non-linearities a quadratic term ROUTLEN2 is included in the specified model.
CD	Carrier intercept terms.[9]

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[7] Empty return ratios (ERRs) were based on a similar parameter used in cost calculations within the Rebee Rail Costing Model. Gross carloads equal (revenue carloads) x (1+ERR).

[8] For example the effect of timetable speed is reflected by the partial derivative of the model equation with respect to TIMETBLS. Normally, this would simply be the estimated coefficient for TIMETBLS, but because of the interaction term, the derivative includes is:

$$\frac{\partial \text{ MAXCARM}}{\partial \text{ TIMETBLS}} = \beta_1 + \beta_2(\text{CTC})$$

[9] A fully interactive model that included interactions between the carrier intercept terms and the other independent variables was tested, but rejected, as it offered no measurable improvement.

A full set of estimation results is provided in Table 2. On the whole, these results support the hypothesized link-specific correlation between observed rail traffic and those variables used to represent the quality and configuration of track structures. We must also conclude, however, that the general degree of model fit and the weak statistical significance of some variables suggests that factors other than track quality and configuration are also important determinants of the level of traffic observed on a particular route segment.

Based on the estimates, the greater train speeds that are facilitated by better track components appear to significantly improve the carload capacity of a network link, while variations in train speed reduce capacity. The coefficient estimates for CTC and ABS clearly indicate that the quality of signaling affects capacity and, as anticipated, the magnitude of CTC is considerably greater than that of ABS. Track capacity is negatively correlated with train length, indicating that, all else equal, it is more difficult to meet and manage trains of greater length. Coefficient estimates for the two interaction terms, CTCSPEED and CTCMAIN, were both negative and statistically significant. Moreover, their magnitudes, relative to estimates for the independent variables from which they are formed, supports the hypothesis that improved signaling increases capacity more when there are fewer mainline tracks or when train speeds are lower, but is a less effective means of adding capacity when multiple main tracks are present or when train speeds are already at relative high levels.[10] The coefficient estimates for SIDSIZ, and SIDINGS display the anticipated signs, although the magnitude and statistical significance of these estimates would, at first glance, appear to under-represent the importance of sidings as a means of adding link capacity.

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[10] While the interaction terms work to offset the individual coefficient estimates, the effects of additional mainline trackage or CTC are still positive. In every case the sum of the interaction terms and independent variables was statistically different from zero at a 95% level of confidence.

Table 2

Variable	*Coefficient Estimate*	*Standard Error*	*"t" (Parm=0)*	*Probability Parm=0*
INTERCEPT	8.289905	0.277913	29.829	0.0001
TIMETBLS	0.033229	0.002437	13.635	0.0001
CTCSPEED	-0.017	0.00365	-4.657	0.0001
SPEEDRAT	0.178289	0.09967	1.789	0.0739
TRAINLEN	-0.00091	6.66E-05	-13.614	0.0001
MAINS	0.7272	0.090022	8.078	0.0001
CTCMAIN	-0.41692	0.131276	-3.176	0.0015
SIDINGS	0.948858	2.394492	0.396	0.692
SIDSIZ	0.095958	0.024872	3.858	0.0001
ABS	0.430842	0.066326	6.496	0.0001
CTC	1.854777	0.177132	10.471	0.0001
SWITCH	0.113847	0.019442	5.856	0.0001
SWITCH2	-0.00517	0.001686	-3.064	0.0022
ROUTLEN	-0.00088	0.001075	-0.815	0.4155
ROUTLEN2	3.46E-06	5.17E-06	0.669	0.5036
CD076	CONFIDENTIAL[11]			
CD190				
CD712				
CD400				
CD555				
CD482				
CD721				
CD802				
Adjusted Model $R^2 = 0.6012$				

The estimation results as depicted in Table 2 are useful in evaluating the overall model performance. However, from the standpoint of assessing track capacity, a series of result applications may be more useful. Tables 3 - 5 illustrate the estimated relationship between independent variables and track capacity as measured by observed traffic under three different circumstances.

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[11] Because confidential Waybill records were used to develop traffic volumes, carrier-specific estimation results are also held to be confidential.

Table 3 illustrates the estimated track capacity for a 100-mile route segment of minimal quality. It is unsignaled, without sidings or additional main tracks, and suitable for train speeds of 20 m.p.h. or less. The estimation results suggest that trackage with this configuration and quality would support roughly five 40 car trains each day.[12] Based on consultation with industry experts, this estimated capacity appears reasonable.

Table 3

Variable/Value	*Measure*	*Variable/Value*	*Measure*
TIMETBLS	20	SIDSIZ	0
CTCSPEED	0	ABS	0
SPEEDRAT	1	CTC	0
TRAINLEN	40	SWITCH	0
MAINS	1	SWITCH2	0
CTCMAIN	0	ROUTLEN	100
SIDINGS	0	ROUTLEN2	10000
Estimated Capacity	17,514		
	5	Trains Per Day	

Table 4 depicts the estimated capacity for a route segment based on the mean values of the independent variables. These data, therefore, depict an "average" route segment based on the sample of roughly 1,300 such segments. As would be expected this typical track segment reflects both better component quality and a more complex configuration. Consequently, it is estimated to accommodate nearly twice the number of daily trains and nearly four times as many cars as the trackage of minimal quality and configuration. Nonetheless, these results do reveal evidence that the data may not be entirely effective at measuring the intended variables. In particular the mean values for SIDINGS and SIDSIZ highlight the lack of specificity that is likely

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[12] Exponentiation of the intercept term reported in Table 3.5 suggests that nearly every piece of trackage, under any configuration and in any condition, will support one train a day.

responsible for the rather lose model fit. It is impossible to discern whether these data reflect 14 equally sized (and very small) sidings or a much smaller number of more usable sidings.

Finally, Table 5 depicts a piece of trackage that is clearly superior to the sample mean. The route in this example is fully signaled with CTC, can accommodate 69 m.p.h. train speeds, and features a significant amount of secondary main, as well as a copious volume of passing track. This trackage is estimated to accommodate more than four times the number of daily trains and train cars hosted by the "average" track depicted in Table 4. Still, consultants, familiar with the industry, have suggested that the trackage portrayed in Table 5 would, in fact, be able to accommodate a volume of traffic that significantly exceed the estimated 40 trains per day. Generally, it is our assessment that the estimation results systematically understate link capacity for higher quality route segments.

Table 4

Variable/Value	*Measure*	*Variable/Value*	*Measure*
TIMETBLS	38	SIDSIZ	0.321
CTCSPEED	14.858	ABS	0.161
SPEEDRAT	0.4848	CTC	0.391
TRAINLEN	79	SWITCH	1.970
MAINS	1.158	SWITCH2	3.881
CTCMAIN	0.452	ROUTLEN	41
SIDINGS	0.108	ROUTLEN2	1681
Estimated Capacity	64,226		
	9	Trains Per Day	

Table 5

Variable/Value	*Measure*	*Variable/Value*	*Measure*
TIMETBLS	69	SIDSIZ	5
CTCSPEED	69	ABS	0
SPEEDRAT	1	CTC	1
TRAINLEN	65	SWITCH	0
MAINS	1.2	SWITCH2	0
CTCMAIN	1.2	ROUTLEN	100
SIDINGS	0.2	ROUTLEN2	10000
Estimated Capacity	236,368		
	40	Trains Per Day	

4. Developing Incremental Capacity Costs

The aim of the current analysis has been to develop an inexpensive and portable method for assessing the incremental cost of additional railroad line-haul capacity. The model estimated within Section 3 illustrates the methods through which capacity can be increased. Within this section, we assign costs to these various methods in order to identify the least-cost method of capacity expansion. The complete process is then illustrated through examples that focus on the upper mid-west.

The cost of building or modifying line-haul railroad trackage is, of course, a function of the quality and configuration of that trackage. It is also, however, affected by a wide array of exogenous factors. Specifically, soil conditions, terrain, environmental concerns, and the degree of urbanization can all significantly impact the cost of a particular construction project. The challenge, within the current context, is to mitigate the effects of these specific factors in order to develop generic cost estimates that can be reasonably applied to a variety of potential infrastructure improvements.

Table 6 provides a summary of the generic or “rule of thumb” measures for costing the construction or modification of rail infrastructure developed by civil engineers the University of Tennessee’s (UT) Transportation Center. Appendix 3 fully documents the methodology, data, and calculations used to produce these estimates. It should be noted, as well, that preliminary estimates were discussed with engineering professionals from a number of Class I railroads and with experts from private construction firms that are routinely engaged in rail project construction. It is, of course, possible to point to innumerable examples of rail infrastructure projects where the actual incurred costs are quite different than those contained within Table 6. We are, however, extremely confident that the UT estimates are both reasonable and reliable.

Table 6 also contains the estimated necessary real rate of return on capital investments. The effect of varying this rate even a little has a significant impact on the final costs of multi-million dollar. It is, therefore, important to carefully select this rate. To simplify its estimation, the analysis ignores the potential impact of expected inflation, focussing instead on the *real* necessary rate of return. It is also important that the identified rate reflect the necessary return under conditions of competitive supply. Any observed impacts that result of the exercise of market power must be eliminated. The necessary rate of return should, instead, be a forward-looking, long-run, least-cost estimate of the cost of capital. Ultimately, after numerous machinations in consultation with a variety of sources, the current analysis settled on a real necessary rate of return of 8%. This figure, in combination with recent price patterns, yields nominal rates of return that are somewhat less than the benchmark rate established by the Surface Transportation Board for the assessment of revenue adequacy, but greater than the historical rates of return for most Class I carriers.

Returning to the expense of actually constructing or modify trackage, the analysis assumes that siding construction varies from main-line construction both in the quality of track components and in their placement. For example, the calculation of siding costs incorporates the use of re-lay (used) rail. It also is based on tie spacings that are greater than those used to support mainline track. Light density trackage is of the construction typically found on long industrial tracks, small branch-lines, or Class III railroad mainlines. This track classification is designed to handle modest tonnages at moderate speeds. The medium density case provides cost calculations for the type of trackage typically found on Class I mainlines. This track will support moderate to heavy traffic at track speeds up to perhaps 60 m.p.h. Finally, the heavy haul case reflects the costs of constructing state-of-the-art trackage capable of handling continuously moving heavy traffic as might be evidenced in the Powder River region or within the northeast

Table 6

Base Case				
Summary	Track $/Mile	Track $/Ft	Turnout cost	Control point cost
Siding Case	$383,730	$73	$98,768	$129,290
Light density case	$411,231	$78	333$92,768	$129,290
Medium density case	$457,013	$87	$98,768	$129,290
Heavy haul case	$489,841	$93	$119,691	$129,290
Variations in Terrain				
	Existing ROW	New ROW		
	Incr. $/Mile	$/Mile		
Flat Terrain		$119,262		
Rolling Terrain	$163,612	$786,241		
Mountainous Terrain	$546,532	$3,795,915		
Isolated Signal Projects[13]				
Signal Upgrades	$605,000			
Finance Costs				
Rate of Return	8%			

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[13] The University of Tennessee output did not specifically include isolated signal project costs. It did, however, contain data detailing the actual costs associated with a handful of such projects. These figures were used by TVA to develop the cost estimate used within the analysis.

corridor. Here, rail weight is assumed to be, at least, 136 lbs., concrete ties are placed along with advanced anchoring systems, and ballast (and sub-ballast) levels are at their greatest.

The application of the UT cost estimates is reasonably straightforward. For example the construction of a one-mile long siding on existing right-of-way over flat terrain would include \$383,730 for actual track construction, two turnouts at \$98,768 each, and two control points (If CTC) at a cost of \$129,290 per location for a total cost of \$839,846. A signal upgrade from ABS to CTC over five miles of trackage would cost 5 x \$605,000 or \$3,025,000. Finally, the new construction of a 10 mile long second medium haul main track through hilly terrain would cost \$12,712,366 for earth work, track installation, turn-outs, control points and signals.

The value of the combining the Section 3 model estimates with the engineering costs developed within this section is best illustrated through an example. Over the past decade, there has been considerable public concern regarding overall transportation capacity in the upper mid-west. Therefore, we focus on that region. Ideally, it would be possible to examine every relevant routing within region. Unfortunately, this is not currently possible. As a second best approach, we elected to focus on a sample of 15 route segments that, together, comprise roughly 750 miles of the 5,000 miles of mainline trackage that connects the upper mid-west to the St. Louis area. These route segments and their characteristics are summarized in Table 7 below. The confidentiality of the waybill records used to develop carload estimates precludes the specific identification of these routes. However, these segments reflect trackage in Illinois, Iowa, Missouri, and Wisconsin and represent properties operated by Burlington Northern - Santa Fe, Union Pacific (traditional), Union Pacific (C&NW), Norfolk-Southern and the Soo Line. Finally, without specific knowledge of the necessary incremental capacity, we proceed through the remainder of this analysis guided by the base-line goal of doubling currently observed capacity.

The similarities and contrasts revealed through a comparison of these route segments are very informative. First, it is clear that the circumstance in which it is easiest to increase capacity is one where the track in question is of modest construction, poorly maintained or otherwise configured in a way so as to provide only nominal current capacity. For example, consider the route segment identified as No. 12 in Table 7. Here, the average timetable train speed is only 16 m.p.h. and the ratio of minimum to timetable speed indicates that a number of trains operate at speeds well below the timetable average. At the same time, the presence of CTC suggests that this was once a route segment intended to accommodate a significant amount of trackage. In an attempt to increase the capacity of this route, we elected to completely overhaul it by installing entirely new medium capacity trackage on the existing right of way, adding two, 10,000-foot sidings, and completing the CTC over the entirety of the route. The costs of these measures would be significant - nearly $22 million in total. However, these expenditures also would purchase a significant increase in annual capacity. Absent the rehabilitation, in its current condition, the route segment can accommodate roughly 160,000 car movements per year. After the track replacement, signal improvements, and siding construction described above, the same route segment is estimated to accommodate more than 375,000 car movements per year. Even assuming a 100% empty return ratio (ERR), the rehabilitated route segment could be used provide over 300 million ton-miles of transportation services. If we assume that, on average, the components of this upgrade will have a productive life of 30 years, then the cost of the incremental track capacity is estimated to be 0.64 cents per ton-mile. A route description and incremental calculations are provided in Table 8.

While the calculations described above are all that is necessary to assess the incremental costs of rail capacity, they do not answer the concerns of most transportation users. From the standpoint of shippers, the 0.64 cents per ton-mile incremental capacity cost is only relevant when viewed in comparison to the capacity costs currently embedded in observed railroad rates. If the incremental cost exceeds current capacity costs, the future average will increase, so that cost-based rates would also be forced to increase. Alternatively, if the incremental cost of the capacity necessary to accommodate increased demand is less than the capacity costs currently embodied within rates, then the future average capacity cost would be lowered and competitively determined rates would decline. While a formal comparison of these costs is beyond the scope of the current research, an arms' length examination suggests that the incremental cost of additional capacity along this route is unlikely to adversely affect competitively determined rates. Using 4.5 cents per ton-mile as a representative rate, traditional rail costing models would assume that roughly two-thirds of this rate is attributable to variable costs, while the remaining 1.5 cents per ton-mile is a necessary contribution toward fixed costs.[14] Determining the precise proportion of that penny and one-half that accounts for the historical cost of line-haul capacity would constitute and arduous (and very probably contentious) accounting exercise.

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[14] While 4.5 cents per ton-mile reflects a men rate across all commodities in all markets, it is not uncommon to observe grain rates that are as low as 1.8 cents per ton-mile or rates for the movement of coal that are in the range of 1.2 cents. Thus, even considering that variable costs for unit train movements of dry bulk commodities are lower than for other movements, it is still apparent that the current methodology provides only a rough approximation of the fixed cost of providing line-haul trackage.

Table 7

Route	*Timetable Speed*	*Minimum / Timetable Speed Ratio*	*Train Length (cars)*	*Number of Mainline Tracks*	*Proportion of Sidings*	*Siding Size*	*Proportion of ABS*	*Proportion of CTC*	*Daily Switch Movements*	*Route Length (miles)*	*Carloads Per Quarter*
1	17	0.26667	64	1.63	0.0991		0.6667	0.3333	0.00	10	47,019
2	64	0.00347	10	1.54	0.0991		0.9412	0.0588	0.00	81	170,826
3	44	1.00000	44	1.23	0.0991	0.210	0.0000	1.0000	0.00	18	101,688
4	33	0.44321	44	1.01	0.0991		0.0000	0.0000	0.06	112	29,199
5	46	0.03111	30	1.74	0.0991	1.613	0.9750	0.0250	2.91	112	165,761
6	59	0.55682	31	2.03	0.1113		0.0000	0.0000	0.00	25	143,544
7	32	0.38450	391	0.87	0.1113		1.0000	0.0000	0.02	33	27,775
8	29	0.31925	9	1.16	0.1113		0.0000	0.0000	0.92	31	30,638
9	29	0.24576	59	1.05	0.1113		0.0000	0.0000	0.28	40	24,258
10	45	0.49551	65	1.42	0.1113		0.0000	0.0000	1.74	8	67,010
11	27	0.34560	18	0.92	0.1280	0.390	0.0000	0.0000	0.97	46	20,197
12	16	0.25597	48	0.38	0.0771	2.920	0.0000	0.8000	2.12	29	39,628
13	19	0.21621	141	0.88	0.0771	0.600	0.0000	0.0000	2.20	91	14,379
14	54	0.62957	23	1.20	0.1241	0.410	0.0000	1.0000	2.78	58	161,393
15	40	0.52895	144	0.96	0.1241		0.0000	1.0000	0.26	79	78,151
Mean	37	0.38151	75	1.20	0.1055	1.024	0.2389	0.2811	0.95	52	54,555

Table 8

Route and Route Characteristics	
State of Operation	Illinois / Iowa
Average Timetable Speed	16.28
Siding Size	2.92
Percent ABS	0
Percent CTC	0.8
Route Length	28.88
Daily Switch Movements	2.11829
Average Train Length	48.119
Train Speed Ratio (Minimum / Timetable	0.25597
Number of Mainline Tracks	0.38129
Proportion of Trackage with Sidings	0.07711
Carloads Per-Year Supported	158,512
Infrastructure Improvement and Costs	
Rebuild Track to Medium Density Standards	17,923,650
Install (2) 10,000' Sidings	1,855,072
Upgrade Remaining Track Signals to CTC	3,978,480
Finance Cost	$35,953,496
TOTAL	57,855,626
Incremental Capacity Improvement	
In Carloads Per-Year	218,514
Percentage of Original	237.85%
In Ton-Miles (100% ERR)	302,912,747
Incremental Per-Ton-Mile Capacity Cost	$0.00637

Nevertheless, the 0.64 cents incremental capacity cost does not, at a glance, appear to threaten markedly higher railroad rates.[15]

It is one thing to indicate that a poorly constructed or maintained piece of trackage could be rehabilitated to provide cost-effective new capacity, but what of those cases where the infrastructure is already of a high caliber? The route numbered 14 in Table 7 provides an ideal opportunity to examine the incremental capacity costs associated with expanding the capacity of

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[15] It is important to recall that the Corps' Principles and Guidelines call for the assumption of adequate capacity unless there is compelling evidence to the contrary.

an already well functioning rail route. In contrast to the first example, average timetable train speeds are at nearly 55 m.p.h. and the variability of observed train speeds is considerably lower. The route is already fully signaled with CTC and there would seem to be few options for increasing route capacity. This route segment typifies the upper end of the medium-haul case described in the UT cost calculations.

The calculations detailed in Table 9 reflect our attempt to transform this route segment into a premium heavy-haul line. Existing trackage is supplemented with the addition of a second 58 mile mainline constructed to heavy-haul standards and two additional 10,000 foot sidings. Additionally, it is assumed that 25% of the new second main must be constructed on newly acquired right of way, so that the per-mile construction cost escalates to $809,110 per mile.[16] The total cost of this rehabilitation is in excess of $145 million. However, as Table 9 indicates the incremental increase in line-haul capacity is estimated to be more than one billion ton-miles per year. Again, assuming a thirty year asset life, the cost of this incremental capacity is estimated to be 0.43 cents per ton-mile, or somewhat less than the incremental cost in the first example.

Table 10 summarizes the incremental cost calculations for each of the 15 sample route segments. On average, under a variety of different scenarios, involving many different carriers, in at least four upper mid-west states, the incremental cost of an additional ton-mile of line-haul capacity is estimated to be 0.395 cents. These estimates clearly indicate that if necessary, Class I rail carriers can add the appropriate volume of new line-haul capacity at a cost that is very unlikely to prove harmful to the overall level of competitively determined rail rates.

Table 9

Route Characteristics	
State of Operation	Missouri
Average Timetable Speed	54.35
Siding Size	0.41
Percent ABS	0
Percent CTC	1
Route Length	58.472
Daily Switch Movements	2.11829
Average Train Length	23.092
Train Speed Ratio (Minimum / Timetable	0.62957
Number of Mainline Tracks	1.2021
Proportion of Trackage with Sidings	0.12409
Carloads Per-Year Supported	524,729
Infrastructure Improvements And Costs	
Construct 2nd Main Track to Heavy-Haul Standards	$53,099,008
Install (2) 10,000' Sidings	$1,855,072
Finance Costs	$90,210,006
TOTAL	$145,164,085
Incremental Capacity Improvement	
In Carloads Per-Year	397,928
Percentage of Original	175.83%
In Ton-Miles (100% ERR)	1,116,847,116
Incremental Per-Ton-Mile Capacity Cost	0.0043

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[16] As with virtually all examples developed in this investigation, it is assumed that the terrain is rolling rather than flat or mountainous. Refer to Appendix 3 for a description of these terrain conditions.

Table 10

Example Number	*Carloads Per-Year Supported*	*Infrastructure Improvement Cost*	*Incremental Capacity Carloads Per-Year*	*Percentage of Original Capacity*	*In Ton-Miles (100% ERR)*	*Incremental Per-Ton-Mile Capacity Cost*
1	188073	$1,803,265	115,713	161.53%	28,215,541	$0.00320
2	683247	$22,868,953	253,507	137.10%	491,722,154	$0.00233
3	406755	$8,649,333	109,972	127.04%	47,692,730	$0.00907
4	116787	$67,808,400	277,048	337.22%	745,236,291	$0.00455
5	663040	$18,016,846	139,169	120.99%	373,851,625	$0.00241
6	574169	$15,246,000	309,220	153.86%	187,016,390	$0.00408
7	111096	$21,547,822	95,028	185.54%	148,471,295	$0.00726
8	122551	$20,489,072	208,620	270.23%	308,423,471	$0.00332
9	97031	$26,879,758	185,548	291.23%	354,737,670	$0.00379
10	268041	$1,053,323	176,578	165.88%	70,857,137	$0.00074
11	80785	$30,896,958	170,487	311.04%	380,281,727	$0.00406
12	158512	$21,902,130	218,514	237.85%	302,912,747	$0.00362
13	57512	$112,058,894	236,902	511.92%	1,039,679,096	$0.00539
14	524729	$54,954,080	397,928	175.83%	1,116,847,116	$0.00246
15	312602	$74,595,039	323,596	203.52%	1,228,304,146	$0.00304
Mean	290995	$33,251,325	214,522	226.05%	454,949,942	$0.00395

5. Summary Remarks

Those familiar with the empirical data and methods commonly used in transportation economics are sure to conclude that the above analysis pushes the available data to the limits of their usefulness and, simultaneously, employs myriad simplifying assumptions that are routinely violated within the day-to-day world of transportation. The ambitious nature of this investigation combined with the paucity of useful information simply demanded that we be both inventive in our approach and accepting of a certain level of imprecision. Thus, the conclusions we draw from this study rest on a relatively fragile analysis. Even, however, after noting this qualification, we remain convinced that both the methods and results reported above represent an effective treatment of railroad capacity.