A SEQUENTIAL LINK APPROACH TO EVALUATING TRANSPORTATION FACILITY ADJUSTMENTS*

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Adjustments in the distribution system, as rapidly and as consistently as they occur, seldom fail to elicit substantial emotional reaction. Linking the production system with the consumption system, the distribution system is extremely pervasive. Small changes have widespread effects. Thorough, objective analysis of these changes is difficult and vulnerable, especially when public hearing procedures provide little time for intensive study.

This article has two objectives. The first is to develop an analytical approach to evaluate changes in transportation facilities, which incorporates the power of marginal investment analysis. The second is to identify and compose quantitative indicators for the chief economic effects of facility changes.

Discussion is limited to additions and deletions of highly durable way and terminal facilities. Focusing upon these infrastructural changes permits discussion of impacts accompanying extensions of highways and waterways; abandonment of railways and roadways; development of seaports and airports; introduction of slurry pipelines and grain conveyors; and restructuring of county rural road systems.

The article begins by proposing a modified benefit-cost analytical procedure for evaluating transportation facility investment projects. Next, effects of facility changes upon market participants and fuel consumption are discussed and quantitative impact measures proposed. Finally, the recommended analytical procedure is applied to evaluate an actual branch line abandonment case as a demonstration of the method.

SEQUENTIAL LINK ANALYSIS

Addition and deletion of transportation way and terminal facilities are typically either performed or regulated by agencies responsible for social welfare. Consequently, these investment and disinvestment projects must be evaluated with the broadest scope allowed by public policy analysis. With an objective to maximize net social benefits from invested resources, decision-makers will seek to adjust facility capacity to maximize

$$NB = (TR-TC)+(TEB-TEC) \qquad (1)$$

subject to

$$NB \geq 0 \qquad (2)$$

The present value of total revenues less total costs of the project, i.e., (TC—TC), represents the net financial gain resulting from operation of the facility. The present value of total external benefits less total external costs, i.e., (TEB—TEC), represents project-related net gains to other participants in the economy. Many transfers of value are accounted for within the latter quantity, many cancelling each other.

A necessary condition for maximizing net benefits from a facility investment is to select facility capacity such that incremental gains from the last capacity unit employed just offset incremental losses.[1] That is,

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[1] A sufficient condition for attaining objectives (1) is

$$(3') \quad \frac{D^2NB}{dC^2} = \frac{dMRP}{dC} + \frac{dMEB}{dC} - \frac{dMC}{dC} - \frac{dMEC}{dC} < 0$$

That is, the rate at which incremental social gains change must be less than the rate at which incremental social costs change. This condition is clearly fulfilled when gains rise with capacity at a diminishing rate and costs increase at an increasing rate.

$$\frac{dNB}{dC} = MRP - MC + MEB - MEC = 0 \qquad (3)$$

where

C = quantity of capacity units
MRP = facility marginal revenue product
MC = facility marginal cost
MEB = marginal external benefits, and
MEC = marginal external costs

Project analysis typically focuses upon maximizing objective function (1) without considering the necessity of fulfilling marginal condition (3) to achieve that objective. Evaluation typically proceeds by defining a limited set of projects, estimating benefit-cost ratios for each project, and ordering alternatives from the highest to the lowest benefit-cost ratio not less than unity. The procedure addresses objective (1) directly by suggesting projects with the highest benefit-cost ratios. Non-negativity condition (2) is satisfied by restricting choice to ratios not less than unity.

The standard procedure is highly vulnerable to the size of projects originally defined. Each may be composed of numerous facilities and activities. A project with some activities yielding gains and other yielding losses will have less social value than an intermediate-sized one containing only activities yielding a net gain. A project with facilities too numerous or too large may yield smaller net gains than one with smaller and fewer facilities. Where the abbreviated, more efficient projects are not originally defined for analysis, these alternatives will not be presented to decision-makers for judgment.

An alternative approach focuses upon fulfillment of marginal condition (3), necessary to achieve objective (1). The procedure begins by defining the smallest practical capacity units for durable facilities and by defining individual activities. Then, alternative projects are designed as ordered sequences of capacity units or activities. For each capacity unit or activity added, two measures of net benefits are obtained. One is a measure of net benefits attributable to the incremental extension. The second is a measure of cumulative net benefits attributable to the entire project. Where both of these measures are positive, the incremental capacity unit or activity is justifiable.

The beauty of the approach lies in its power to evaluate all intermediate project alternatives. The disadvantage is that every permutation of capacity units and activities which potentially comprise a project must be evaluated. For large projects encompassing numerous construction programs and numerous activities, number of permutations for evaluation is awesome.[2]

EVALUATING TRANSPORTATION FACILITY ADJUSTMENTS

The linear character of transportation facilities limits number of practical permutations to manageable analytical capabilities. The smallest facility capacity unit is a way segment leading to a traffic generating point and associated terminal facilities, hereafter called a link enterprise. An investment project is an ordered sequence of link enterprises. A sequence of transportation links has a very limited and ordered pattern, being connected end-to-end, with some branching.

Sequential link analysis requires both an incremental and a cumulative net benefit accounting for each link enterprise added. For the incremental account, marginal revenue product equals present value of total revenue generated from traffic originating and terminating at terminal facilities on the incremental link enterprise. Marginal cost is the present value of costs associated with establishing, maintaining, and operating the incremental link enterprise with expected traffic volume. Marginal external benefits and costs are those which result with construction and operation of the additional link facility that would not occur without the extension. The sum of these values must be nonnegative to fulfill marginal condition (3).

For the cumulative net benefit account, total financial and external values are calculated for the entire sequence of links from the project origin through the incremental link enterprise being evaluated. The total net benefit account must be non-negative to fulfill condition (2).

Analysis does not cease when one of the two criteria fails for a link producing low traffic volume. Subsequent link additions may produce high traffic volumes which more than offset intervening losses.

Linear transportation facilities permit traffic to pass in two directions. A one-way analysis, assuming that all traffic moves in one direction toward central arteries, is typically valid when evaluating railroad branch line abandonments, waterway and highway extensions, long-distance grain conveyors and slurry pipelines. If substantial traffic moves toward the terminus of a branch, one-way analysis remains valid when intra-branch traffic is assigned to the link

[2] A group of n activities can be aligned in n! ordered sequences.

farthest from the central artery and such traffic is not double-counted.

Two-way analysis is required when evaluating railway and highway additions connecting arterial facilities.[3] This is basically a set of two one-way branch analyses, one moving traffic in each possible direction. A slight difference enters when the last connecting link is considered, as it has no distinct revenue generating point. The benefit accruing to this connecting link is the present value of operating cost savings, due to reduced circuitry of movement on the transportation system.

A hypothetical application of sequential link analysis will illustrate the procedure. Suppose a railroad firm has applied to abandon line segment AC, intersecting the mainline at station A. Suppose, also, that a government agency wishes to decide whether to buy the line to assure continued service. The present value of financial and external benefits attributable to each link are indicated in Figure 1. The railroad is willing to sell the line for $5,000 per mile. Since each link in the example is one mile in length, buying branch AC requires that benefits generated on incremental link BC equal or exceed $5,000 and that cumulative benefits on the entire branch equal or exceed $10,000.

In panel (a), benefits equivalent to $9,000 are generated on link AB and $2,000 on link BC. The cumulative benefit criterion is met with $11,000. The incremental criterion is not satisfied with only $2,000 generated on link BC. Continued operation of link BC would generate a loss which could be avoided by abandoning the link. The sequential link approach would suggest buying and operating link AB and closing link BC. Standard benefit-cost analysis of the

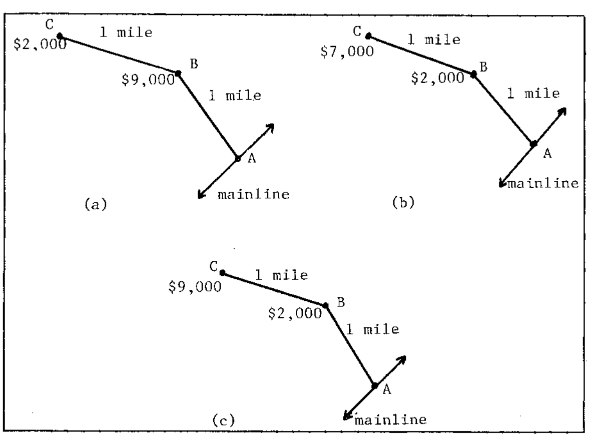

FIGURE 1.

originally defined project to buy line AC would show benefits of $11,000 and costs of $10,000 yielding a benefit-cost ratio of 1.1. Using standard procedures, the entire branch might be recommended for purchase.

Panel (b) represents a case in which the incremental benefit criterion on link BC is fulfilled, but the cumulative benefit criterion is not. Only $9,000 in benefits are generated on the entire branch line. While substantial traffic and external benefits are generated on link BC, these are not adequate to support the entire branch; traffic and spin-off effects on intervening links (AB) are not sufficient to make up the difference. Neither the sequential link approach nor the standard approach to evaluation would support acquisition of any part of the line.

Panel (c) represents a situation in which both incremental and cumulative benefit criteria are fulfilled. Benefits generated on incremental link BC equal $9,000. Benefits on the entire branch equal $11,000. Link BC itself does not generate benefits adequately to justify purchase of the entire branch, but benefits on intervening links are sufficient to make up the difference. Both approaches to evaluation would support purchase and operation of line AC.

Comparing panels (a) and (c), one notes how the position of weak links in benefit generation affects their viability in service. In panel (c), link AB satisfies neither incremental nor cumulative benefit criteria. However, continuation on link BC makes the entire line viable. Link BC effectively subsidizes link AB, but this subsidy is unavoidable. Train service on link AB is a joint product with service on link BC; costs associated with link AB cannot be allocated to individual links.

The converse is not true. Service on link BC is not entirely a joint product with service on link AB; costs associated with link BC are identifiable by link and therefore are avoidable by abandonment. Though cumulative benefits are equal in panels (a) and (c), sequential link analysis would support closure of link BC in panel (a) and continued operation of link BC in panel (c). The standard approach to project evaluation would be unable to distinguish these two cases.

IMPACTS OF FACILITY ADJUSTMENTS

Transporation facility adjustments have a broad array of effects upon many aspects of the economy. Some impacts can be measured quantitatively, with

[3]John O. Gerald suggested the necessity of two-way analysis for complete evaluation of connecting line and mainline projects.

reasonable accuracy. Other effects can be evaluated only qualitatively. While both quantitative and qualitative accounts can be constructed on both incremental link and cumulative link bases, only effects with quantitative measures are discussed here. Quantitative measures can be used to determine effects upon (1) modal transportation markets, (2) producers and consumers of commodities and (3) energy consumption.

MODAL TRANSPORTATION MARKETS

Evaluating effects of transportation facility changes upon the various modal transportation markets amounts to comparing equilibrium conditions within the transportation industry, with and without a proposed change. Supply and demand conditions in the modal market being adjusted provide a basis for financial analysis of the intended project. Effects of adjustment upon supplies and demands in the remaining modal markets provide a basis for evaluating effects upon substitute modes, upon transportation users, and upon tertiary community activities.

The multi-market impact of adjustment in one modal market is seen with the aid of Figure 2. Assume the existence of only two modes in the region, W and R. The market for services of mode R is in equilibrium at price p_r^o and quantity q_r^o. Mode W is in market equilibrium at price p_w^o and quantity q_w^o.

Suppose extension of services to new locations lowers long-run average cost of mode W from LAC_w^o to LAC_w'. Average costs may decline with incremental way and terminal extensions, because much of transportation service is produced jointly by hauling goods to numerous locations simultaneously. If one considers a distribution service with assembly and long-haul services, extensions of long-haul facilities may reduce average distribution costs by reducing assembly activities. A lower long-run average cost suggests that supply of service can be shifted from S_w to S_w', at which a new equilibrium is established at price p_w' and quantity q_w'.

The lower equilibrium price in market W causes an increase in quantity of service demanded. Part of the traffic increase is newly generated shipments brought about by introduction of freight rates lower than previously experienced; another part is traffic diversions from substitute mode R. At any price of service R, less quantity is demanded; demand shifts back from D_r to D_r'. Reduced demand causes market price of service R to fall to p_r', below that required to maintain firms in the industry. The least efficient firms, and those caught with untenable cash flow positions, exit the market; supply shifts back from S_r

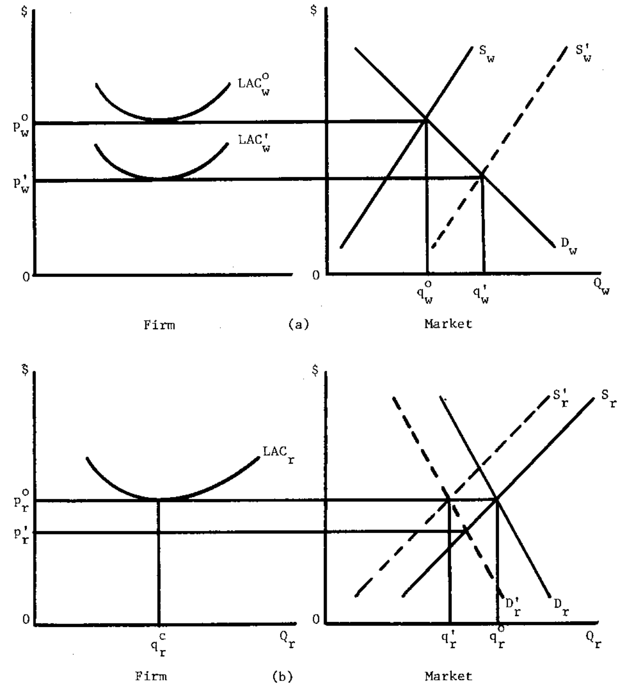

FIGURE 2.

to S_r', restoring equilibrium price, p_r^o, at a reduced service level, q_r'.

Minor capacity adjustments in response to permanent traffic diversions do not have a devastating effect upon the economy when service capacity is relatively divisible, as in the trucking industry. More substantial effects may result where capacity is highly indivisible. Where traffic supporting a modal service is already thin, reduction in demand for services can create a condition in which no shift in supply will restore equilibrium at a price and quantity combination where revenues cover costs. Abandonment of service and facilities ensues.

Every mode requires a critical mass of traffic for viability. Erosion of this traffic base, resulting from adjustments in facilities of other modes, may drive an entire modal market out of a region. One must be particularly cognizant of market skimming in this regard. For example, if long-distance grain covenyors skim volume grain traffic from railroads, a vast system of branch lines may be left to serve only a few lumber yards and small, rural manufacturers. By economizing on a specialized movement, a versatile mode capable of serving a variety of traffic may be left non-viable. These situations require broad system evaluations, comparing present value of total costs of shipping a variety of commodities by railroad versus shipping one bulk commodity by a cheaper means and all residual traffic by more expensive means.

In practice, one is limited in ability to evaluate comparative, multiple market equilibria. Some important aspects can be estimated, however. With knowledge of freight rates, traffic diversions can be estimated. For facility extensions, some shipments will be diverted to new lower cost facilities. For facility abandonments, shipments will be diverted to the next least costly mode, except for shippers exiting the region. Revenue diversions between modes can be estimated by multiplying volume of traffic diverted by freight rates of donor and recipient modes. This procedure also provides an estimate of traffic which will be diverted to new facility extensions. Lacking are measures of new traffic generations and of old traffic discouragement resulting from shippers leaving a region.

PRODUCERS AND CONSUMERS OF COMMODITIES

The transportation system connects producers and consumers of commodities. Producers perceive and respond to demand prices diminished by transport costs. In Figure 3, commodity market equilibrium exists at quantity q^o when unit transport cost equals $t^o = p_d^o - p_s^o$. Introduction of a new transportation mode reducing unit transport costs to $t' = p_d' - p_s'$ yields a market exchange level of quantity q'. Two benefits accrue to producers and consumers. First a transport cost savings, equal to $(t^o - t')q^o$, is offered on original traffic volume. This comes in the form of price decreases to consumers or price increases to producers. Distribution of transport cost savings depends upon supply and demand elasticities in the commodity market.

Secondly, increased output is generated. Producers benefit in a magnitude equal to profits on the incremental units (triangle ABC); consumers benefit in a magnitude equal to consumers' surplus (triangle DEF). The sum of these benefits represents net market benefit to producers and consumers in each period. The present value of this stream of net benefits over the horizon, less initial investment cost of the new facility, is the net economic gain to the commodity market resulting from facility adjustment. Abandonment of a low-cost transport mode yields losses of equivalent magnitudes.

In practice, change in transport costs is readily obtainable from the financial analysis of a new facility, and from data on next least costly modes in the case of facility abandonments. Anticipated output expansions or contractions, resulting from transportation price changes, must be estimated using supply and demand elasticities for particular commodity markets.

The total net gain to the market economy of a

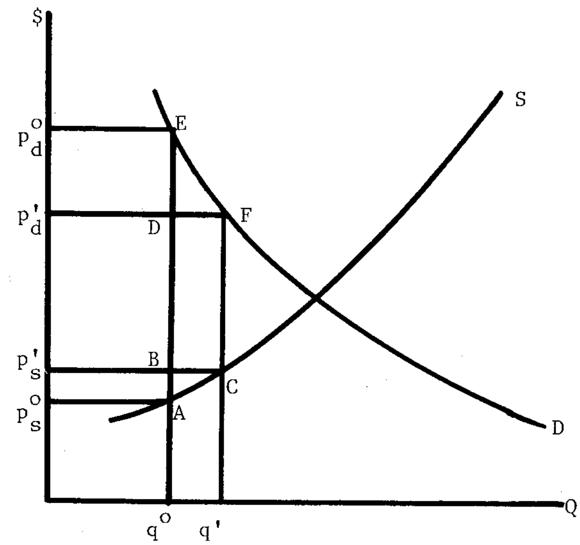

FIGURE 3.

transportation facility change equals the present value of producers' and consumers' surpluses described in this section. All other value elements are merely transfers between consumers, producers of commodities and producers of transportation services.

ENERGY USAGE

A useful nonmonetary indicator of stress put upon energy resources as a result of transportation facility adjustments is the resultant change in gallons of fuel consumed. This can be calculated by determining the difference in gallons of fuel used with and without the adjustment. Gallons of fuel consumed are estimated by dividing ton-miles of transportation service performed by each mode, by the respective transportation-energy efficiency ratio. The ratio is typically reported in units of ton-miles of output per gallon of fuel input.

The value placed upon this nonmonetary measure of energy effects must reflect only the demand for fuel preservation over time. Value of fuel in current use is already considered in fuel prices, composing a portion of operating costs implicitly considered in the discussion of transportation markets.

AN EMPIRICAL APPLICATION

To demonstrate the form of analytical results obtainable with the sequential link approach, the procedure is used to evaluate effects of a transportation facility change upon market participants and upon fuel usage. Consider a railroad branch line abandonment proposal on the Grand Trunk Western line from St. Johns to Lowell, Michigan (see Figure 4).[4]

[4] This demonstration is produced in greater detail in [1].

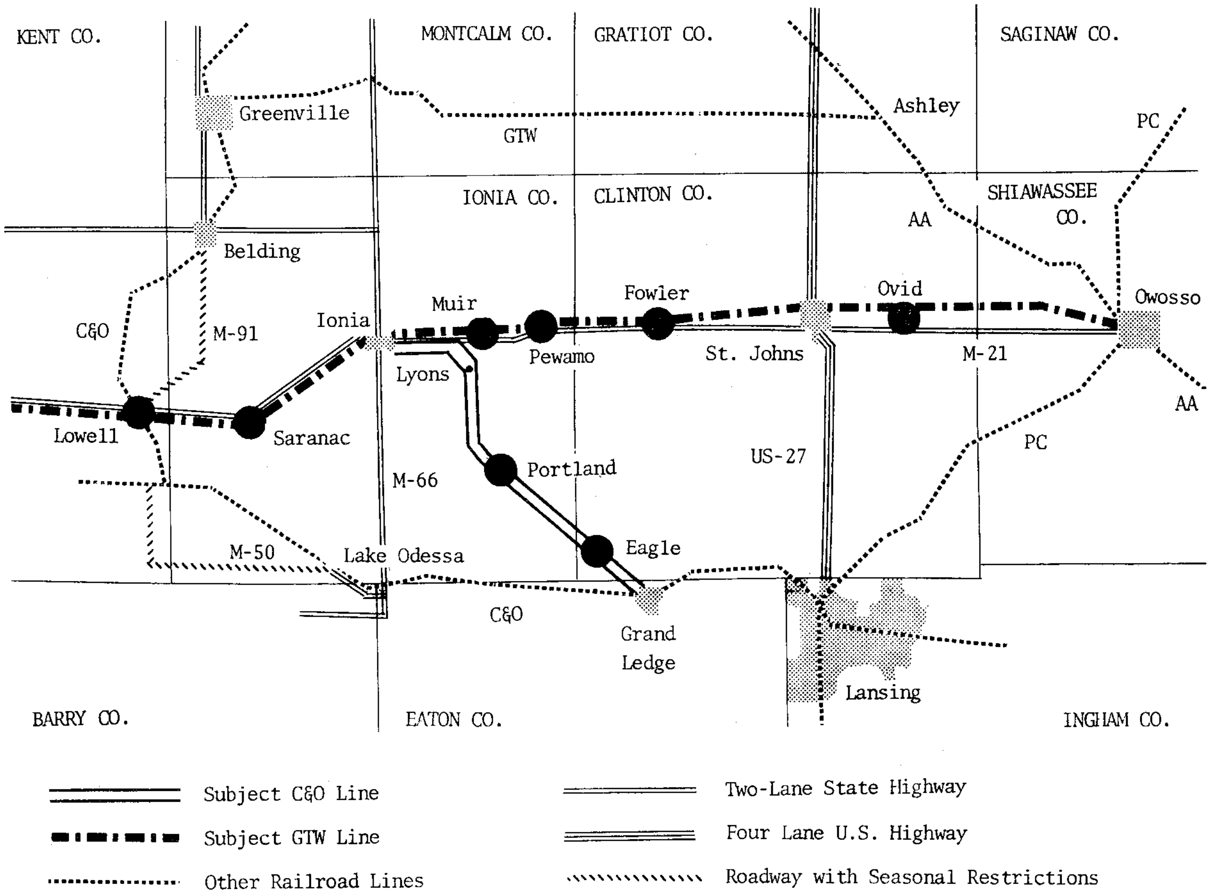

FIGURE 4.

The first four numerical columns of Table 1 display the results of financial analysis on the line. The upper panel provides incremental link values; the lower shows cumulative values. Liquidation value denotes the present value of net material salvage income and future maintenance cost and rehabilitation cost savings avoidable by abandoning the line. Net operating revenue is the present value of operating revenues less operating costs (a stationary traffic stream without abandonment is assumed at 1973 traffic levels for this example). Liquidation value less net operating revenue yields the net financial value of continuing the line operation. Viewing column 3, one notes that neither incremental nor cumulative benefit accounts are positive for continuation of the first three links. Railroad opportunity losses of ending the line at Fowler, Pewamo or Muir are shown as the negative cumulative values of net market value, in the lower panel.

Both incremental and cumulative criteria are met with addition of the rail link to Ionia. This signifies that traffic generated at Ionia is strong enough to support both the 8.3 miles of track leading to Ionia, and the deficit on the remaining 20.4 miles of track from St. Johns. Continuation of service to Ionia appears best for the railroad with a net value of $318,000. Continuation of the line to Saranac and Lowell is unprofitable, since the incremental benefit criterion on that link is negative; the additional link enterprise causes an avoidable decline in line value of $196,000.

Impacts of the abandonment upon other transportation modes appear very slight. Some traffic is diverted to trucking and piggybacking, chiefly from manufacturing firms and animal feed stores. The greatest gains from abandonment accrue to the Chesapeake and Ohio Railroad (C & O) on the link serving Ionia. All Grand Trunk Western (GTW) traffic at Ionia would be consolidated onto the C & O line. Receivers of farm machinery, bulk fertilizer and lumber in towns losing their only railroad will order railroad delivery at nearby stations and transfer materials to local dealerships by truck. With the proposed abandonment, these dealers in Fowler would receive materials at the GTW station at St. Johns. The GTW loses no revenue on these shipments, though dealers incur added transshipment costs. These dealers in Pewamo and Muir would divert their

TABLE 1. MARKET EVALUATION OF A 42.9 MILE GRAND TRUNK WESTERN LINE FROM ST. JOHNS TO LOWELL, MICHIGAN: STATIONARY TRAFFIC ASSUMED*

Station (Miles)	Liquidation Value Less Land Value	Net Operating Revenue	Net Market Value	Net Market Value Per Mile	Potential Revenue Enhancement	Potential Market Value	Potential Market Value Per Mile
Marginal Link Valuation							
Fowler (10.0)	$152,401.83	$ 31,308.75	-$121,093.08	-$12,109.31	$ 78,813.80	-$ 42,279.28	-$ 4,227.93
Pewamo (5.8)	$ 75,869.94	$ 41,269.75	-$ 34,600.19	-$ 5,965.55	$ 76,058.30	$ 41,458.11	$ 7,147.95
Muir (4.6)	$ 56,710.74	$ 51,392.25	-$ 5,318.49	-$ 1,156.19	$ 60,000.00	$ 54,681.51	$11,887.28
Ionia (8.3)	$119,978.47	$598,816.50	$478,838.03	$57,691.33	$ 0.00	$478,838.03	$57,691.33
Saranac-Lowell (14.2)	$236,579.60	$ 40,475.50	-$196,104.10	-$13,810.15	$ 22,312.50	-$173,791.60	-$12,238.84
Cumulative Link Valuation							
Fowler (10.0)	$152,401.83	$ 31,308.75	-$121,093.08	-$12,109.31	$ 78,813.80	-$ 42,279.28	-$ 4,227.93
Pewamo (15.8)	$228,271.77	$ 72,578.50	-$155,693.27	-$ 9,854.00	$154,872.10	-$ 821.17	-$ 51.97
Muir (20.4)	$284,982.51	$123,970.75	-$161,011.76	-$ 7,892.73	$214,872.10	$ 53,860.34	$ 2,640.21
Ionia (28.7)	$404,960.98	$722,787.25	$317,826.27	$11,074.09	$214,872.10	$532,698.37	$18,560.92
Saranac-Lowell (42.9)	$641,540.58	$763,262.75	$121,722.17	$ 2,837.35	$237,184.60	$358,906.77	$ 8,366.13

*Calculations are based upon actual 1973 traffic flows.

shipments to the C & O station at Lyons. Since the C & O is a much larger system than the GTW, larger proportions of total railroad system net revenues will be attributed to the C & O line than were previously attributed to the GTW line. Traffic added to the C & O line from Ionia, Muir and Pewamo yields a present value of $2.22 million in new freight revenues, assuming a stationary traffic trend.

Column five of Table 1 records the impact of line abandonment upon producers and consumers. Each entry represents the present value of increased freight costs, summed over all shipper firms, resulting from the proposed abandonment. The column is labeled "potential revenue enhancement," for these values approximate the upper limit by which local shippers would be willing to increase freight expenses—or to subsidize line retention—in order to avoid shifting to next least costly modes.

The sum of columns three and five represent net value of line retention to the railroad, producers and consumers. These incremental and cumulative "potential market values" are shown in column six. After internalizing effects upon producers and consumers, link enterprises serving Fowler and Pewamo are not justifiable. A project of retaining the line to Muir is justifiable by both incremental and cumulative criteria, only after the $215,000 in producer and consumer losses with abandonment offset the $161,000 opportunity loss to the railroad with service continuance. Even after internalizing producer and consumer losses, continuation of the line to Saranac and Lowell is not justifiable.

Computation of added fuel consumption implied by the railroad abandonment west of St. Johns is displayed in Table 2. Upon line closure, traffic is shifted to next least costly modes. Animal feed and some manufactured goods are diverted to motor carriage. Outbound grain shipments are trucked to the nearest terminal elevator. Bulk fertilizer, lumber and machinery are brought to the nearest station by railroad and delivered to local retailers by truck. All traffic in Ionia moves to the C & O railroad. Added truck ton-miles and reduced railroad ton-miles are calculated, as in columns two and four. These ton-mile figures are divided by transportation-fuel efficiency ratios to yield changes in fuel consumption by each mode, as in columns three and five. The difference provides an estimate of net change in fuel consumption, recorded for incremental links in column six and for cumulative link sequences in column seven. For the entire line abandonment, an annual increase of 2,400 gallons of fuel usage is expected.

TABLE 2. EFFECTS OF ABANDONMENT UPON ANNUAL FUEL USAGE: GRAND TRUNK WESTERN FROM ST. JOHNS TO LOWELL, MICHIGAN*

Station	Total Ton-Miles	Added Truck Ton-Miles	Added Truck Fuel (Gallons)	Reduced Railroad Ton-Miles	Reduced Rail-Road Fuel (Gallons)	Annual Net Added Fuel Usage (Gallons)	
						Individual Link	Cumulative
Fowler	1,451,460	202,080	1,981	202,080	594	1,387	1,387
Pewamo	554,460	61,760	605	61,760	182	423	1,810
Muir	2,995,066	840	8	840	2	6	1,816
Ionia	0	0	0	0	0	0	1,816
Saranac	89,250	89,250	875	89,250	262	613	2,429

*Calculations are based upon actual 1973 traffic flows.

CONCLUSIONS

The linear character of transportation facilities provides opportunity for more highly refined project analyses of facility changes than other types of projects permit. The limited number of ways in which a sequence of transportation links can be constructed allows evaluation of transportation projects using a sequential link approach. The approach focuses upon fulfillment of marginal conditions necessary to attain project objectives. The sequential link approach provides a mechanism to evaluate each step of project construction and to identify the appropriate size of projects within the analytical procedure. This approach differs from standard benefit-cost analysis, in which a limited number of projects of given sizes are defined prior to evaluation. Sequential link analysis has been shown, in this article, to be more sensitive to the distribution of benefits across links within a project, than is standard benefit-cost analysis. Standard procedures have also been shown to give erroneous results, caused by giving attention only to aggregate accounts in disregard for separate link enterprise accounts.

REFERENCES

[1] Johnson, Marc A. *Community Evaluation of Railroad Branch Lines: Principles and Procedures*, Center for Rural Manpower and Public Affairs, Bulletin No. 38, Michigan State University, April 1975.