TRANSPORTATION RESEARCH RECORD 828

Analysis of Transportation Investment and Use

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1981

Transportation Research Record 828
Price $4.20
Edited for TRB by Naomi Kassabian

modes
1 highway transportation
3 rail transportation

subject area
15 socioeconomics

Library of Congress Cataloging in Publication Data
National Research Council (U.S.). Transportation Research Board. Meeting (60th: 1981: Washington, D.C.)
Analysis of transportation investment and use.

(Transportation research record; 828)
Reports presented at the 60th annual meeting of the Transportation Research Board.
1. Transportation–Congresses. 2. Transportation–Finance–Congresses. I. Title. II. Sereis.
TE7.H5 no. 828 [HE11] 380.5s 82-6335
ISBN 0-309-03270-9 ISSN 0361-1981 [380.5'9] AACR2

Sponsorship of the Papers in This Transportation Research Record

GROUP 1–TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Leon M. Cole, Library of Congress, chairman

Social, Economic, and Environmental Factors Section
Clarkson H. Oglesby, Stanford, California, chairman

Committee on Passenger and Freight Transportation Characteristics
W. Bruce Allen, University of Pennsylvania, chairman
Peter M. Montague, Federal Railroad Administration, secretary
A. Don Bourquard, Leland S. Case, Steven W. Fuller, Arthur F. Hawnn, Lloyd R. Henion, David A. Isacowitz, I. Bernard Jacobson, Frank E. Jarema, William A. Lesansky, Edward Margolin, Edward K. Morlok, Richard R. Mudge, Jerold B. Muskin, Howard E. Olson, Paul O. Roberts, Robert Torene, Marcus Ramsay Wigan

Task Force on Economic Analysis
Gary R. Allen, Virginia Highway and Transportation Research Council, chairman
W. Bruce Allen, Daniel Brand, Ken Casavant, John J. Coyle, Curtis A. Cramer, Charles W. Dale, John F. Due, Martin T. Farris, Hays B. Gamble, Charles A. Hedges, Lowell D. Hill, Damian J. Kulash, Edward Margolin, John C. Spychalski, William S. Vickrey, Martin Wohl

Task Force on Motor Vehicle Size and Weight
John W. Fuller, University of Iowa, chairman
Arthur J. Balek, Byron C. Blaschke, Charles N. Brady, Dock Burke, William A. Goodwin, Peter Griskivich, William D. Hart, Clifford J. Harvison, Perry M. Kent, Donald F. Kuster, Robert Davis Layton, R.V. LeClerc, Donnell W. Morrison, Dale E. Peterson, John L. Reith, Freddy L. Roberts, Thurman D. Sherard, Fred Lee Smith, Jr., Andrew St. John, Joseph G. Stieber, Carl N. Swerdloff, Guy Trepanier, Patricia F. Waller, C. Michael Walton, Leonard B. West, Jr., Robert P. Whorf

Floyd I. Thiel and David C. Ewing, Transportation Research Board

Sponsorship is indicated by a footnote at the end of each report. The organizational units, officers, and members are as of December 31, 1980.

Contents

Authors of the Papers in This Record

Ben-Akiva, M., Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139
Blechinger, Wolfgang, Socialdata GmbH, Hans-Grässel-Weg 1, 8000 München 70, Federal Republic of Germany
Blow, Philip W., Federal Highway Administration, U.S. Department of Transportation, Washington, DC 20590
Brög, Werner, Socialdata GmbH, Hans-Grässel-Weg 1, 8000 München 70, Federal Republic of Germany
Chiang, Y.S., Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139
Huber, Klaus, Zentrale Verkaufsleitung Deutsche Bundesbahn, Rhabanusstrasse 3, 650 Mainz 1, Federal Republic of Germany
Roberts, Paul O., Jr., Booz, Allen and Hamilton, Inc., 4330 East-West Highway, Bethesda, MD 20014
Talley, Wayne K., Department of Economics, Old Dominion University, Norfolk, VA 23508
Walton, C. Michael, Department of Civil Engineering, University of Texas at Austin, Austin, TX 78712
Wohl, Martin, Transportation Systems Center, U.S. Department of Transportation, Kendall Square, Cambridge, MA 02142
Yu, Chien-Pei, Center for Transportation Research, University of Texas at Austin, Austin, TX 78712

Abridgment

Methodologies for Transportation Cost Analysis: A Survey

WAYNE K. TALLEY

The purpose of this paper is to present various methodologies that have been used for analyzing transportation costs as well as to discuss their merits and shortcomings with respect to the following purposes of transportation cost analysis: (a) to investigate such broad issues as economies of scale and production properties of transport firms and (b) to determine specific (or fully allocated) costs for particular transportation movements. The methodologies have generally been of three types—engineering, accounting, and economic. The principal conclusions of the paper are that (a) economic cost functions or economic cost functions in conjunction with engineering models are the desirable methodologies for investigating economies of scale and production properties of transportation firms and (b) accounting costing is a desirable methodology for determining fully allocated costs of transportation movements.

Analyzing transportation costs is often difficult because (a) the output of a transportation firm is multidimensional by its very nature and (b) transportation activities are characterized by common costs. The transportation firm provides different types of services for different users not only at different origins and destinations but also at different levels of quality. Even though the above difficulties exist, transportation costs have been analyzed for basically two purposes: (a) to investigate such broad issues as economies of scale and production properties of transportation firms (for example, separability, homogeneity, and nonjoint production) and (b) to determine specific costs (or fully allocated costs) for particular shipments and trips (in order to determine the maximum reasonableness of rates, profits, or deficits from particular movements and to investigate the existence of cross-subsidization, etc.).

The purpose of this paper is to present various methodologies that have been used for analyzing transportation costs as well as to discuss their merits and shortcomings with respect to the above purposes of transportation cost analysis. The methodologies have generally been of three types--engineering, accounting, and economic.

ENGINEERING COSTING

In order to analyze transportation costs by using an engineering approach, one must first specify the relevant engineering (or physical) relationships among inputs, outputs, and quality-of-service characteristics (or combinations of the above). The functions for such relationships may be derived from physical laws or estimated from sample observations. For example, Hennes and Ekse (1, Chapter 25) present such a relationship for resistance to train movement (in pounds per ton of train weight) as a function of average weight per axle in tons, speed in miles per hour, number of axles per item of equipment, etc. Examples in which engineering relationships are estimated are given by DeSalvo and Lave (2) and by Daughety and Turnquist (3).

Engineering models of the operations aspect of a firm provide information but an incomplete picture of the firm. Such models consider physical processes at the firm but not such nonoperations activities as planning and sales. On the other hand, such activities are captured to some degree by the economic models. Daughety and Turnquist (3) suggest that engineering-process models be used as constraints on cost models in order to define implicitly the technology to which the cost model is dual and thus to derive a better-specified cost model. Specifically, Daughety and Turnquist (3) use engineering-process models to estimate train speeds, which are in turn used in rail cost functions to estimate various rail cost. Further discussion of relationships between engineering and economic activities may be found in a paper by Marsden, Pingry, and Whinston (4).

One possible shortcoming in attempting to use an engineering model to develop a transportation cost function is that market prices may not exist for one or more of the physical inputs; i.e., the inputs in an engineering production function are not necessarily market inputs. Alternatively, inputs in an economic production function are market inputs for which market prices are expected to exist, as discussed by Chenery (5). Hence, if market prices do not exist for engineering inputs, difficulties arise in assigning costs to these inputs and thus in determining the costs of providing given transportation movements. In an engineering cost analysis of motor carriers by Schuster (6,7), prices for the inputs were presumably available. Furthermore, such engineering models would be precluded from investigating pecuniary economies of scale but not technological economies of scale. Pecuniary economies of scale are associated with the ability of a large firm to affect the prices for which it purchases inputs.

ACCOUNTING COSTING

Accounting costing by its very nature seeks to determine the costs of given transportation services. A cost function that relates cost to output is not developed as in the sense of engineering and economic cost functions. By using cost-accounting principles, the accountant assigns to a particular transportation movement the costs that are traceable to that movement as well as a share of common costs that the movement incurs with other movements. Thus, accounting costing may and has been used to determine specific costs (or fully allocated costs) for particular transportation shipments and trips. Applications of cost accounting in transportation cost analyses are given by Dierks (8), Cherwony (9), Whitten (10), and Young (11). A new rail costing system, referred to as the Uniform Railroad Costing System, to be used by the Interstate Commerce Commission (ICC), is basically an accounting costing procedure. This new system is designed to provide the ICC with more-specific costs on particular railroad movements.

One potential shortcoming of accounting costing is that the recorded book costs of assets may not be an accurate guide to the actual opportunity costs of these assets. Since opportunity costs are the relevant ones for decisionmaking, accounting costs may need modification to reflect actual opportunities foregone. However, since accounting data are often used in engineering and economic costing, this potential shortcoming is not unique to accounting costing.

Another potential shortcoming relates to how the accountant establishes cost accounts or categories. The fundamental purpose of accounting is to systematically order and record the financial transactions of a firm. However, the accounts may be established so that there is little correspondence between cost categories and specific transportation movements. Thus, in such circumstances, the accounts will be unable to reveal accurately either the level of cost associated with a particular transportation movement or the level of costs incurred in common with other transportation movements.

In addition to the possibility that cost accounts may be established arbitrarily, the rules for determining how common costs are to be shared among particular transportation movements are generally established arbitrarily. Accounting rationale may be given for the establishment of such rules but not an economic rationale. This point is discussed by Braeutigam (12). A final shortcoming of accounting costing is that without the formal specification of a function that relates cost to output, this costing approach is not conducive to investigating such broad issues as economies of scale and production properties of transportation firms. It has also been argued that accounting costing is a deviation from the economic theory of cost, since marginal costs of transportation services cannot be obtained.

ECONOMIC COSTING

When economic costing is proposed for analyzing transportation costs, it is generally assumed that the parameters of a cost function that relates cost to output are to be estimated. In order to use economic cost functions to analyze transportation costs, one must first specify the form of such functions. In the transportation cost literature, three general functional forms have been considered:

1. Linear functions, which assume that a straight-line relationship exists between costs and output;
2. Nonlinear functions, which assume that a curved relationship exists between cost and output; and
3. Polynomial functions, which include linear terms as well as higher-order nonlinear terms.

The linear specification is restrictive in that marginal costs are assumed to be the same at all levels of output. Alternatively, the nonlinear specification allows marginal cost to vary with output. The nonlinear specification has been limited primarily to those nonlinear forms that have exponential parameters and it thus restricts cost elasticity with respect to output to be constant. This nonlinear specification and the linear specification also impose the restriction of homotheticity; i.e., regardless of the size of a transportation firm, the proportional mix of inputs will remain the same. In contrast, polynomial functional forms may be specified so that the restrictive assumptions of homotheticity and constant marginal cost are not imposed. Examples of such functional forms are given by Spady and Friedlaender (13,14).

In addition to function specification, measurement of transportation output for the cost function also has to be considered. One of the earlier attempts to identify the proper unit of measurement for transportation output was made in a paper by Wilson (15), who argued that the sales unit (or the ton mile) was the appropriate output measurement for freight transportation. Waters (16) states that a ton mile that involves opposite directions is not the same product nor is the movement of a ton mile of perishable commodities necessarily the same output as the movement of a ton mile of bulk materials. Further, the quality of service for ton miles may differ according to speed, flexibility, and other characteristics of service.

In a paper by Spady and Friedlaender (14), a particular type of polynomial cost function is presented that attempts to account for quality differences in transportation services. The functional form is a hedonic trans-log function. The function is hedonic in that cost is a function of an effective output (or hedonic function), which in turn is a function of a generic measure of physical output and its qualities. For example, Spady and Friedlaender (14) express effective output as a function of ton miles and some of their various characteristics as average shipment size, average length of haul, average load, etc. Other applications of the use of trans-log functions in analyzing transportation costs are given by Daughety and Turnquist (3); by Oum (17); by Brown, Caves, and Christensen (18); by Caves, Christensen, and Swanson (19); and by Spady and Friedlaender (13).

With transportation firms providing a wide range of outputs at different levels of quality, it is virtually impossible to introduce specific variables in the cost function for each type of output. Hence, Spady and Friedlaender (13, p. 28) conclude that aggregation of factors and outputs is necessary. However, aggregation itself presents problems in terms of not only which cost accounts to aggregate but also what functional form of aggregate functions to use. Spady and Friedlaender (13) conclude that there is really no alternative but to assume homothetic aggregation functions. Further discussion of aggregation functions may be found in papers by Samuelson and Swamy (20), by Fisher (21), and by Spady and Friedlaender (13, pp. 28-30).

If one rejects homothetic aggregation, there is not generally any aggregation function that exists that has desirable properties with respect to measurement scale, etc. Thus, in the absence of homothetic aggregation, one must use totally disaggregate data (which is generally infeasible in view of the large number of different inputs and outputs associated with transportation firms). Alternatively, if one ignores the restrictions imposed by homothetic aggregation and simply adds together ton miles or freight cars, it is likely that extreme biases will result in the estimated cost or production functions.

With aggregation being necessary in order to estimate transportation cost functions, merits as well as shortcomings arise in using such functions to analyze transportation costs. In using aggregated data, economic cost functions (especially trans-log functions) may be used to investigate economies of scale for transportation firms, to predict aggregate costs as a basis for comparative evaluation of different firms or operations, and to test for separability, homogeneity, and nonjoint production in transportation. Further discussion of these topics may be found in a report by Spady and Friedlaender (13).

Shortcomings from aggregated cost functions are primarily concerned with the inability of such functions to predict disaggregated costs and therefore to determine costs of particular transportation movements (or fully allocated costs). Furthermore, these functions would not be an appropriate means of allocating common costs among transportation movements that incur these costs in common, since the functions were estimated by using aggregate rather than disaggregate data.

ACKNOWLEDGMENT

This paper was written while I was a faculty fellow at the Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts.

REFERENCES

1. R.G. Hennes and M. Ekse. Fundamentals of Transportation Engineering. McGraw-Hill, London, 1969.
2. J.S. DeSalvo and L.B. Lave. A Statistical Engineering Approach to Estimation of Railway Cost Functions. Rand Corp., New York, NY, 1968.
3. A.F. Daughety and M.A. Turnquist. Development of Hybrid Cost Functions from Engineering and Statistical Techniques: The Case of Rail--First Year Final Report. Transportation Center, Northwestern Univ., Evanston, IL, 1979.
4. J. Marsden, D. Pingry, and A. Whinston. Engineering Foundations of Production Functions. Journal of Economic Theory, 1974, pp. 124-140.
5. H.B. Chenery. Engineering Production Functions. Quarterly Journal of Economics, Vol. 63, No. 4, Nov. 1949, pp. 507-531.
6. A.D. Schuster. An Economic Analysis of Motor Carrier Less-Than-Truckload Transportation Services. Ohio State Univ., Columbus, Ph.D. dissertation, 1977.
7. A.D. Schuster. Statistical Cost Analysis: An Engineering Approach. Logistics and Transportation Review, Vol. 14, No. 2, 1978, pp. 151-164.
8. P.A. Dierks. Applying Cost Accounting to Transit System Financing. Management Accounting, Vol. 60, No. 6, Dec. 1978, pp. 20-23.
9. W. Cherwony. Cost Centers: A New Approach to Transit Performance. Transit Journal, Vol. 3, No. 4, Fall 1977, pp. 70-80.
10. H.O. Whitten. Functional Cost Accounting for Railroads. ICC Practitioners Journal, Vol. 43, March 1976.
11. R. Young. A New Regulatory Accounting System for Railroads. ICC Practitioners Journal, Vol. 43, May 1976.
12. R.R. Braeutigam. An Analysis of Fully Distributed Cost Pricing in Regulated Industries. Bell Journal of Economics, Vol. 11, No. 1, Spring 1980, pp. 182-196.
13. R.H. Spady and A.F. Friedlaender. Econometric Estimation of Cost Functions in the Transportation Industries. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, Sept. 1976.
14. R.H. Spady and A.F. Friedlaender. Hedonic Cost Functions for the Regulated Trucking Industry. Bell Journal of Economics, Vol. 9, No. 1, Spring 1978, pp. 159-179.
15. G.W. Wilson. On the Output Unit in Transportation. Land Economics, Vol. 35, No. 3, Aug. 1959.
16. W.G. Waters II. Statistical Costing in Transportation. Transportation Journal, Vol. 15, Spring 1976, pp. 49-62.
17. T.H. Oum. A Cross-Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada. Bell Journal of Economics, Vol. 10, No. 2, Autumn 1979, pp. 463-482.
18. R.S. Brown, D.W. Caves, and L.R. Christensen. Modeling the Structure of Cost and Production for Multiproduct Firms. Southern Economic Journal, Vol. 40, No. 1, July 1979, pp. 256-273.
19. D.W. Caves, L.R. Christensen, and J. Swanson. Productivity in U.S. Railroads, 1951-1974. Bell Journal of Economics, Vol. 11, No. 1, Spring 1980, pp. 65-83.
20. P.A. Samuelson and S. Swamy. Invariant Economic Index Numbers and Canonical Duality: Survey and Synthesis. American Economic Review, Vol. 64, 1974, pp. 566-593.
21. F.M. Fisher. Approximate Aggregation and the Leontief Conditions. Econometrica, Vol. 37, July 1969, pp. 457-469.

Publication of this paper sponsored by Task Force on Economic Analysis.

Abridgment

New Ranking Procedure and Set of Decision Rules for Method of Internal Rate of Return

MARTIN WOHL

A new ranking procedure and revised set of decision rules have been developed for the method of the internal rate of return. Their application will lead to a clear-cut and proper decision about acceptability and about the best alternative, at least as long as the minimum attractive rate of return is at least as large as the borrowing rate for capital that must be acquired outside the firm or agency.

I will not argue here about which economic analysis method (e.g., internal rate of return, net present value, or benefit/cost ratio) is preferable but instead will outline a new ranking procedure and a new set of decision rules for the method of internal rate of return in order to ensure that the decisions that result from its use are always correct and unambiguous. Of some importance, this discussion will be limited to cases in which the minimum attractive rate of return (MARR) will be at least as large as the borrowing rate (BORR) for capital that must be acquired outside the firm or agency. [For a discussion of the case in which MARR < BORR see the Discussions and Closures included with the paper by Wohl (1).]

SITUATIONS THAT CAN LEAD TO AMBIGUOUS OR INCORRECT DECISIONS

One situation that sometimes leads to incorrect or ambiguous decisions is that in which there is more than one internal rate of return for a given alternative. Specifically, whenever the net annual cash flows during the n-year analysis period (i.e.,

Table 1. Annual cash flows for bridge improvement.

End of Year t	B_t[a] ($000s)	C_t[b] ($000s)	$B_t - C_t$ ($000s)
0	-	50	-50
1	61	55	+6
2	63	0	+63
.	.	.	.
.	.	.	.
.	.	.	.
9	77	0	+77
10	79	705	-626
11	81	610	-529
12	83	495	-412
13	85	0	+85
.	.	.	.
.	.	.	.
.	.	.	.
29	117	0	+117
30	119	0	+119

Notes: Internal rates of return r are 8.52, 18.66, and 73.57 percent. $[NPW]_{0\ percent} = +785$.
[a]Benefits during year t, net of annual maintenance and operating costs.
[b]Nonrecurring costs during year t.

Table 2. Annual cash flows for local streetcar-line extension.

End of Year t	B_t ($000s)	C_t ($000s)	$B_t - C_t$ ($000s)
0	0	175	-175
1	0	1265	-1265
2	250	0	250
3	240	0	240
4	230	0	230
5	220	0	220
.	.	.	.
.	.	.	.
.	.	.	.
19	80	0	80
20	70	0	70
21	60	0	60
22	0	1900	-1900

Notes: r = 3.85 and 4.99 percent. $[NPW]_{0\ percent} = -240$.

Table 3. Annual cash flows for oil-pump alternatives.

	Alternative 1		Alternative 2		
Year	$B_{1,t}$	$C_{1,t}$	$B_{2,t}$	$C_{2,t}$	$\Delta B_t - \Delta C_t$[a]
0		100		110	-10
1	70		115		+45
2	70		30		-40

Notes: $[NPW_x]_{0\ percent} = +40$ for alternative 1, +35 for alternative 2. r_x or Δr, $r_1 = 25.69$ percent, $r_2 = 26.16$ percent, $\Delta r = 21.92$ and 228.08 percent.
[a]$\Delta B_t = B_{2,t} - B_{1,t}$ and $\Delta C_t = C_{2,t} - C_{1,t}$.

$B_t - C_t$ for $t = 0,\ldots,n$) are such that there are two or more sign changes, the possibility of multiple nonnegative internal rates of return arises. An example of this case is shown in Table 1 and might apply when a two-stage improvement program for an existing highway or bridge (e.g., minor repairs now and a major overhaul later) is analyzed. In this instance, an incorrect or ambiguous economic decision could result if the MARR were, say, 10 percent. Would one reject the project or not? Without additional information, the choice is not clear.

A second but different example of the above case is shown in Table 2. Such a situation might arise if a transit company was granted a 22-year franchise and allowed to build a streetcar line on the condition that the streetcar tracks had to be removed and the street returned to its original condition at the end of the 22-year franchise. Again, it is not clear how these two internal rates of return should be interpreted. If, for instance, the MARR were 3 percent, should we accept or reject the project?

The third situation in which difficulties can arise is that which involves incremental analysis between pairs of alternatives. Briefly, variations in benefit-accrual patterns as well as fluctuations in cost outlays can lead to multiple internal rates of return for the increments in benefit and cost between the two alternatives being compared. Fourth, erroneous decisions can result from ambiguities about how to rank alternatives that have equal initial costs.

The oil-pump example in Table 3 is the third type of situation. Briefly, the extra investment for a larger oil pump leads to an overall increase in oil production but, more importantly, permits earlier extraction of most of the remaining deposits. As a consequence, the incremental net cash flows (i.e., $\Delta B_t - \Delta C_t$ for $t = 0,1,2$) shown in Table 3 indicate two sign reversals and thus the possibility of two nonnegative incremental rates of return. In this case, there were two such rates, 21.92 percent and 228.08 percent. In turn, we must ask how to interpret the two rates. If the MARR was about 20 percent, one would probably conclude that alternative 2 (i.e., the larger oil pump) was economically preferable. That is, since $r_1 >$ MARR, alternative 1 is acceptable; since both values of Δr (the internal rates of return on the increments in cost and benefit) are greater than MARR, one presumably would regard alternative 2 as better than alternative 1 or one would regard the choice as ambiguous.

REVISED RANKING PROCEDURE

First, let me define the procedure for ranking mutually exclusive alternatives for the purpose of determining which alternative is best.

1. Determine the net present worth (NPW) for each alternative that is being analyzed at a 0 percent interest rate; that is, simply sum the net (undiscounted) annual cash flows for the n-year analysis period, or

$$[NPW_x]_{0\ percent} \sum_{t=0}^{n} (B_{x,t} - C_{x,t}) \quad (1)$$

where $B_{x,t}$ and $C_{x,t}$ are the benefits and costs, respectively, for project x during year t of the n-year analysis period and $[NPW_x]_{0\ percent}$ is the NPW for project x at an interest rate of 0 percent.

2. Rank all alternatives in ascending order with respect to the above $[NPW_x]_{0\ percent}$ values. It is important to note that the resultant ranking can and often will differ markedly from the usual (but undesirable) ranking rule, which calls for ordering according to the initial year's costs or outlays. For instance, the above set of ranking rules would reverse the usual ranking of the alternatives as they are shown in Table 3.

REVISED DECISION RULES FOR DETERMINING ACCEPTABILITY

1. Determine $[NPW_x]_{0\ percent}$ as indicated in Equation 1.

2. Determine r_x, the internal rate of return for alternative x (i.e., determine the discount rate or rates at which the discounted benefits just equal the discounted costs over the n-year planning horizon). If there are multiple rates of return, list them in ascending order, as follows: r_x', r_x'', r_x''', r_x'''',...; however, exclude all nonpositive rates.

3. When $[NPW_x]_{0\ percent} \neq 0$, accept or re-

ject alternative x according to the following rules:

Condition	Slope: $[NPW_x]_{0\ percent}$ > 0	$[NPW_x]_{0\ percent}$ < 0
MARR < r_x or MARR < r_x'	Accept	Reject
r_x' < MARR < r_x''	Reject	Accept
r_x'' < MARR < r_x'''	Accept	Reject
r_x''' < MARR < r_x''''	Reject	Accept
Etc.	Etc.	Etc.

4. When $[NPW_x]_{0\ percent} = 0$, first determine the slope of the NPW function for an interest rate of 0 percent, as follows:

$$\text{Slope of } [NPW_x]_{0\ percent} = -\sum_{t=1}^{n} t(B_{x,t} - C_{x,t}) \quad (2)$$

In turn, accept or reject alternative x according to the following rules when there are multiple rates of return:

Condition	Slope: Greater Than Zero	Less Than Zero
MARR < r_x'	Accept	Reject
r_x' < MARR < r_x''	Reject	Accept
r_x'' < MARR < r_x'''	Accept	Reject
r_x''' < MARR < r_x''''	Reject	Accept
Etc.	Etc.	Etc.

Also, when there is only one internal rate of return and thus r_x is equal to 0 percent, accept the alternative when the slope is positive and reject the alternative when the slope is negative.

5 Whenever all internal rates of return are negative or indeterminate, accept alternative x if the $[NPW_x]_{0\ percent}$ is nonnegative (i.e., ≥ 0) and reject it if the $[NPW_x]_{0\ percent}$ is negative.

REVISED RULES FOR DETERMINING BEST ALTERNATIVE

1. Determine $[NPW_x]_{0\ percent}$ for all mutually exclusive alternatives.
2. Rank the alternatives in ascending order with respect to the NPW at 0 percent (i.e., $[NPW_x]_{0\ percent}$ for all x). However, if the NPW values for two or more alternatives are equal, determine the slope of the NPW function at 0 percent (as shown in Equation 2) and rank them in ascending order with respect to the algebraic value of the slopes; that is, the alternative that has the most-positive (or least-negative) slope will be the highest-ranked al- ternative.
3. Determine the incremental internal rate of return for increments in benefits and costs between the lowest-ranked pair of alternatives or Δr_{1-2}; if there are multiple incremental rates of return, list them in ascending order as follows: $\Delta r_{1-2}'$, $\Delta r_{1-2}''$, $\Delta r_{1-2}'''$,...; however, exclude all nonpositive rates.
4. Accept or reject the higher-ranked alternative of the two being compared according to the following rules:

Condition	Rule
MARR < Δr_{1-2} or MARR < $\Delta r_{1-2}'$	Accept
$\Delta r_{1-2}'$ < MARR < $\Delta r_{1-2}''$	Reject
$\Delta r_{1-2}''$ < MARR < $\Delta r_{1-2}'''$	Accept
$\Delta r_{1-2}'''$ < MARR < $\Delta r_{1-2}''''$	Reject
Etc.	Etc.

5. Apply the above acceptability test to successively higher-ranked alternatives until the highest-ranked alternative is found that is more acceptable than lower-ranked ones. That is, if alternative 2 is more acceptable than alternative 1, then apply the test to determine whether alternative 3 is more acceptable than alternative 2, and so forth. But if alternative 2 is rejected in favor of alternative 1, then compare alternatives 1 and 3 to determine whether alternative 3 is more acceptable than alternative 1.
6. Whenever all incremental internal rates of return are negative or indeterminate, the higher-ranked alternative (according to the rule cited above in Equation 2) will always be preferable.

SUMMARY

The new ranking procedure and set of decision rules for applying the method of the internal rate of return to the evaluation of mutually exclusive alternatives has been described in some detail. Its use will ensure that the economic decisions resulting therefrom (about acceptability and which project is best) will be identical to those that will prevail from use of either the benefit-cost-ratio or net-present-value methods.

ACKNOWLEDGMENT

This paper was written while I was on leave from Carnegie-Mellon University. I am grateful to my colleague, Tung Au, for bringing the modifications noted in this paper to my attention. Were it not for his careful and painstaking review, I would have overlooked the cases when roots are negative or indeterminate.

REFERENCE

1. M. Wohl. Common Misunderstandings About the Internal-Rate-of-Return and Net Present Value Economic Analysis Methods. TRB, Transportation Research Record 731, 1979, pp. 1-19.

Publication of this paper sponsored by Task Force on Economic Analysis.

Abridgment

AASHTO Red Book Application: Economic Analysis of Third Columbia River Bridge

PHILIP W. BLOW

The economic analysis portion of the Columbia River Bridge Feasibility Study, required by the U.S. Congress, is described. The study to assess the feasibility of a third bridge between Vancouver, Washington, and Portland, Oregon, had four components: (a) interviews with state and local officials, (b) a review of reports to assess the demand for travel between the two cities and the capacity of existing and proposed transportation facilities for serving that demand, (c) an economic analysis of a third bridge, and (d) a review of funding available for its construction. The economic analysis followed the procedures outlined in the 1977 American Association of State Highway and Transportation Officials Manual on User Benefit Analysis of Highway and Bus-Transit Improvements. This paper treats the estimation of traffic for this analysis in detail.

This economic analysis was to give scale to the economic feasibility of an additional highway bridge across the Columbia River (1). As such, it did not attempt to distinguish the relative economic efficiency among several possible building alternatives, and consequently it considered only one such alternative for comparison with the alternative of not building a bridge. The analysis followed the procedures outlined in the American Association of State Highway and Transportation Officials (AASHTO) Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (2). The approach was to determine the annual road-user benefits, or the difference in user costs for each of three vehicle types between the alternatives of building or not building over the anticipated life of the facility. The stream of annual user benefits and the proposal's residual value were reduced to their present values and compared with the present values of the costs to construct, operate, and maintain the facility.

TRAFFIC DATA

The traffic data, taken from a Washington State Legislative Transportation Committee study report, included 1977 and 2000 average-weekday-traffic (AWD) estimates for the alternative of not building and the eight alternatives of building, including the location selected for analysis for the congressional study. The third river crossing was assumed to be open to traffic in 1995 and to have a service life of 50 years. Since traffic estimates were not available for after 2000, basic traffic growth assumptions were required for the period 2000-2045.

For the alternative of not building, traffic was assumed to increase at the annual compound rate, 1.75 percent, until the capacity (120 000) of the I-5 bridge would be reached in 2002. From 2002 to 2045 the rate, 0.75 percent, was assumed.

For the alternative of building, traffic was assumed to increase at the annual compound rate, 2.00 percent, but for this study's alternative of building this rate of growth was continued until the combined capacity (200 000) of the existing and proposed bridges would be reached in 2025. From 2025 until 2045 the rate, 0.75 percent, was again assumed for the remainder of the study period. Traffic estimates for the alternative to build represented the total traffic on both bridges, and since each bridge was assumed to have the same ratio of volume to capacity, their total volume and total capacity were used in analyzing the alternative to build. These traffic-growth and capacity assumptions resulted in the AWD estimates for each year shown in Figure 1.

The AASHTO manual uses the volume-to-capacity (V/C) ratio as the primary factor in determining roadway-user costs. The daily traffic volumes were assigned to two periods--peak and off-peak--for this analysis. V/C ratios were computed for the two alternatives, the two daily traffic periods, and the four analysis years (1995, 2002, 2025, and 2045), which correspond to the discontinuities in the traffic projections in Figure 1.

By defining peak-period traffic as K(AWD), where K is the ratio of peak-period traffic to daily traffic, and by assuming that all daily traffic occurred in 18 h of the day, the off-peak-period hourly traffic would be [(1 - 2K)(AWD)]/16. All peak-period traffic was assumed to occur uniformly across 1 h for each period until it exceeded the hourly capacity. Consequently, the traffic volume would remain at capacity but the excess peak-period traffic would spread to each side of the peak hour. The duration (D) of one peak period for this case was calculated based on equivalent areas (Figure 2). That is, by definition, as follows:

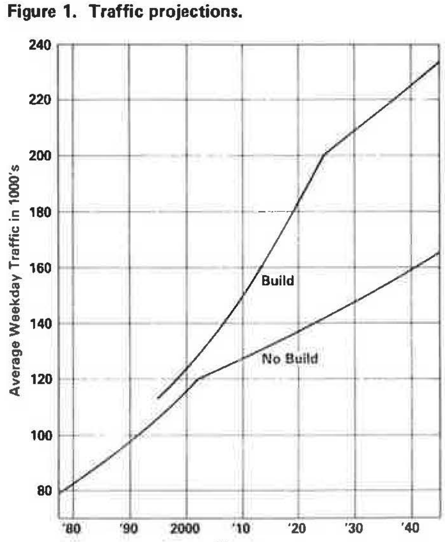
$$1 \times K(AWD) - (1 - 2K)(AWD)/16 = D \times \text{hourly capacity} - (1 - 2K)(AWD)/16 \quad (1)$$

Therefore,

$$D = [K(AWD) - (1 - 2K)(AWD)/16] / [\text{hourly capacity} - (1 - 2K)(AWD)/16] \quad (2)$$

Consequently, the duration of the two peak periods is 2D and the duration of the off-peak traffic periods is 18 - 2D. Table 1 summarizes the volume of hourly traffic, the duration of peak and off-peak periods, and the ratios of volume to capacity.

Figure 1. Traffic projections.



ANALYSIS PARAMETERS

The AASHTO analysis procedure requires the parameters given below:

1. Discount rates: 5, 10, and 15 percent
2. Travel-time costs
   a. Automobiles, $3.98/vehicle-h
   b. Single-unit truck,$9.91/vehicle-h
   c. Truck combinations, $11.33/vehicle-h
3. Analysis period: 1995-2045 (50 years)
4. Analysis intervals: 1995-2002, 2002-2025, 2025-2045
5. Construction cost
   a. Bridge, $46 118 750
   b. Connections, $19 101 000
   c. Total, $65 219 750
6. Net increase in
   a. Annual operating cost, $25 000
   b. Maintenance cost, $28 700
7. Residual value: $48 913 812
8. Project length: 5.8 km

For the analysis, the travel-time values were taken from the manual and adjusted upward for automobile occupancy and inflation. Construction and maintenance cost estimates were based on unit costs available in Federal Highway Administration (FHWA) headquarters. The increase in facility operating cost was based on the assumption that two person-years would be needed. The residual value was estimated by using percentages of the initial costs for the structure, right-of-way, pavement, and engineering. [These cost estimates are detailed in the section on benefits and costs (2).] All dollar values were adjusted to reflect 1979 prices.

USER COSTS

Basic Section Cost

The AASHTO manual (2) provides user costs attributable to a highway section based on vehicle type. To take advantage of this, the traffic stream was split among the vehicle types: automobiles, pickup trucks, and small vans (Auto), 93 percent; single-unit trucks that have dual wheels (SUT), 3 percent; and combination trucks (CT), 4 percent. This was based on a total truck factor of 7 percent and a 41-59 percent split between single-unit and combination trucks.

The basic section cost has four components: tangent-running cost, travel-time cost, speed-change cost, and added-curve cost. The following parameters and assumptions were used in developing these costs:

1. Tangent-running costs were developed for each vehicle type by using curves established for six-lane freeways that have a 90-km/h speed limit on level grade.
2. Travel time was developed by using the same parameters as those for the tangent-running cost and was converted to travel-time cost in dollars by the travel-time cost values previously determined.
3. The lower curve for speed-change cost was used from the AASHTO manual until the V/C ratio reached 1. Then both curves were read, one for just before the traffic would break down (level of service E) and one for just after traffic would break down (level of service F). The E-value was used for the end year of the analysis interval and the F-value was used for the beginning year of the next analysis interval.
4. Running cost on curves was neglected.

Accident Costs

Accident costs for urban expressways used in this analysis were derived from the AASHTO manual. Under this approach, accident rates per million vehicle kilometers by accident type (fatal, injury, and property-damage-only) and costs per accident type were applied to total vehicle kilometers.

Total (Highway) User Costs

Two additional categories of costs--transition cost and intersection-delay cost--would normally be included in an analysis of this type, but these were neglected for this analysis. Once the individual cost components had been determined, the unit highway user costs (HU) for operating on the entire section were determined by applying Equation 3:

$$HU = (B + A)L + T + D \quad (3)$$

where

HU = total unit highway user operating cost for section,
B = basic section cost,
A = accident costs,
L = section length (5.8 km),
T = section transition cost = 0, and

Figure 2. Peak spreading.

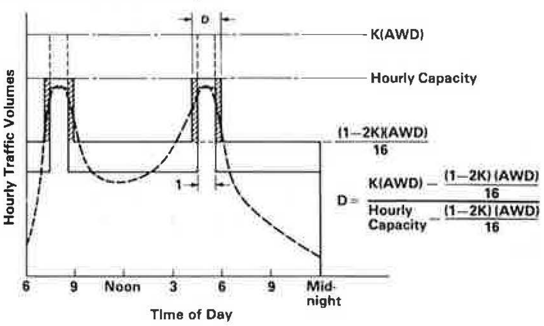
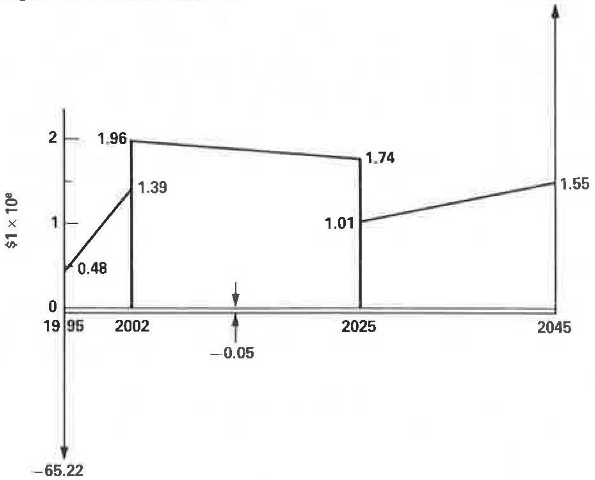


Table 1. Traffic data.

Year	Alternative of Not Building: Peak Period: Hourly Volume (000s)	D	Ratio, V/C	Off-Peak Period: Hourly Volume (000s)	18-2D	Ratio, V/C	Alternative of Building: Peak Period: Hourly Volume (000s)	D	Ratio, V/C	Off-Peak Period: Hourly Volume (000s)	18-2D	Ratio, V/C
1995	10.6	2.0	0.9	5.3	16	0.44	11.3	2	0.6	5.65	16	0.3
2002	12	2.0	1.0	6.0	16	0.5	12.8	2	0.6	6.4	16	0.3
2025	12	3.0	1.0	7.15	15	6.0	20.0	2	1.0	10.05	16	0.5
2045	12	4.4	1.0	8.25	11.6	6.9	20.0	2.8	1.0	11.65	15.2	0.6

Figure 3. Cash-flow diagram.



D = intersection delay cost = 0.

BENEFITS AND NONUSER COSTS

User Benefits

Annual user benefits for each vehicle type within each traffic period for each analysis year were determined by using Equation 1 in the AASHTO manual. This formula is restated as Equation 4:

$$\text{User benefits} = H_{TP}(U_{NB} - U_B)(V_{NB} + V_B)/2000 \quad (4)$$

where

H_{TP} = number of hours in year for given traffic period,
U_{NB} = user cost per 1000 vehicles under alternative of not building,
U_B = user cost per 1000 vehicles under alternative of building,
V_{NB} = traffic volume under alternative of not building, and
V_B = traffic volume under alternative of building.

To calculate the annual user benefits for the study years 2025 and 2045, an additional traffic period was required, since the peak period for the alternative of not building was longer than the one for building. For this intermediate period, peak-period traffic volumes and costs were used for the alternative of not building and off-peak-period traffic volumes and costs were used for the alternative of building.

Construction Cost

The bridge was assumed to have a 120-m lift span that cost $5 000 000, a remaining length of 1934 m, a width of 22.5 m, and a unit cost of $1060/m². This gives a total cost for the bridge of $46 126 000. The connections had an assumed length of 3.7 km and a unit cost of $5 160 473/km for a cost of $19 093 750. The total construction cost was $65 219 750.

Residual Value

This analysis assumed that the project had 75 percent of its original value at the end of its life in 50 years. The bridge itself would retain approximately three-fourths of its original value. Right-of-way, which was estimated as roughly 15 percent of total cost, was expected to maintain its value; pavement and engineering, which together were roughly 7 percent of the total cost, would have no value. Therefore, the residual value would be $48 914 812.

Annual Operating and Maintenance Costs

The annual operating and maintenance costs of the alternative of building were expected to exceed the costs for the alternative of not building by an amount equal to these costs for the new bridge and connections. The total of these costs was $53 700. The cash-flow diagram (Figure 3) represents the expected stream of benefits and expenditures over the life of the project.

PRESENT VALUES AND ECONOMIC DESIRABILITY

The benefits shown in Figure 3 along with the costs were reduced to their present value in 1979 dollars by assuming that the user benefits are increasing or decreasing gradients for the appropriate interval and by applying the appropriate discount factors. The costs and residual value were similarly reduced to their present values for various discount rates and appropriate time periods. Rather than select a specific discount rate, rates of 5, 10, and 15 percent were used to observe how sensitive the analysis was to the discount rate.

Based strictly on an economic analysis, a third bridge across the Columbia River was not feasible. The net present values at the discount rates of 5, 10, and 15 percent were $-35 512 506, $-52 124 552, and $-57 555 828, respectively.

REFERENCES

1. Columbia River Bridge Feasibility Study. FHWA, U.S. Department of Transportation, Jan. 1980.
2. Manual on User Benefit Analysis of Highway and Bus-Transit Improvements. American Association of State Highway and Transportation Officials, Washington, DC, 1977.

Publication of this paper sponsored by Task Force on Economic Analysis.

Abridgment

Short-Run Freight-Demand Model: Joint Choice of Mode and Shipment Size

Y.S. CHIANG, PAUL O. ROBERTS, JR., AND M. BEN-AKIVA

An important part of any quantitative analysis of freight transportation is a capability for forecasting the demand for a certain type of service under a given set of conditions. Unfortunately, the state of the art in freight-demand modeling is still rather primitive. It is clear that the firm is the basic decision-making unit in the transportation of freight. However, the role of the firm in selecting freight transportation service has not been explored satisfactorily. Most of the existing freight-demand models are correlative rather than explanatory and insensitive to changes in transport level-of-service measures. Researchers in the past have been constrained either to piecing together useful aggregate data to estimate an aggregate demand model or to using shipper surveys to estimate a very limited shipper-choice model. An attempt to develop a freight-demand model that involves the choice of mode as well as shipment size without imposing the assumption of constant transportation rate is given. A multinomial logit model of mode and shipment size is developed at the level of the individual firm. The utility function is derived from logistics inventory theory that considers explicitly the trade-offs the firm can make in response to a short-run change in transportation level of service. The major assumption is that the substitution between transportation and other factors of production, such as labor and capital, is relatively inelastic when compared with the substitutions that can take place within the transportation sector itself.

An important part of any quantitative analysis of freight transport is a capability for forecasting the demand for a certain type of service under a given set of conditions. Unfortunately, the state of the art in freight-demand modeling is still rather primitive. It is clear that the firm is the basic decision-making unit in the transportation of freight. However, the role of the firm in selecting freight transportation service has not been explored satisfactorily. Most of the existing freight-demand models are correlative rather than explanatory and insensitive to changes in transportation level-of-service measures. This is primarily due to two factors. The first is the data limitations. Data that can be used to undertake a careful estimation of a disaggregate behavioral freight-demand model are almost nonexistent. Thus, researchers in the past have been constrained either to piecing together useful aggregate data to estimate an aggregate demand model (1-3) or to using inadequate shipper surveys to estimate a very limited shipper-choice model (4,5).

A second limitation comes from the fundamental difficulties that most researchers have experienced in attempting to apply economic theories of derived demand to freight-demand analysis without making unattractive simplifying assumptions. One frequently used assumption is constant transport cost. That is, the freight rate is assumed not to be influenced by the quantity shipped. This makes the model policy insensitive to changes in the transportation level of service (6).

This paper represents an attempt to develop a freight-demand model that involves the choice of mode as well as shipment size without imposing the assumption of constant transport rate. A multinomial logit model of mode and shipment size is developed at the level of the individual firm. The utility function is derived from logistics inventory theory, which considers explicitly the trade-offs the firm can make in response to a short-run change in transportation level of service. The major assumption is that the substitution between transportation and other factors of production, such as labor and capital, is relatively inelastic when compared with the substitutions that can take place within the transportation sector itself.

MODEL FORMULATION

A short-run logistics choice involves the choice of mode (m), shipment size (q), and point of supply (i) given the annual use rate of inputs by the firm (x). The annual use rate, or the level of input, is treated as given. The firm exercises logistics strategies to minimize its purchase and logistics costs for these inputs. Thus, the variables i, m, and q define the possible alternative logistics strategies open to a firm. An optimal strategy is said to be one that has the lowest total purchase and logistics costs. Mathematically, that is as follows:

$$w = \min_{i,m,q} w_{imq} [P_{iq}(x) + T_{imq}(x)] \quad (1)$$

where w is annual total cost for an input commodity, P is purchase costs, and T is logistics costs.

There appear to be two general approaches one can take in modeling the logistics decision of a firm. The difference between the two approaches lies in the assumption involved in the level of certainty concerning the information in the logistics cost function given in Equation 1. In the first approach, the logistics cost function is assumed to be fully observable. Therefore, the alternative defined by the choice of i, m, q is selected with certainty if $w_{imq} < w_{i'm'q'}$, $\forall i'm'q' \in A$, where A is the choice set. A model developed on this assumption can be referred to as a deterministic cost model of short-run freight demand (7).

The second approach assumes that the logistics cost function is not fully observable. Only part of the cost function is observed. Denoting w_{imq}^{o} as the observable part of the logistics cost function and w_{imq}^{u} as the unobservable part of the logistics cost function, we have $w_{imq} = w_{imq}^{o} + w_{imq}^{u}$ $\forall imq \in A$. The unobservable part is assumed to be a random variable. Thus, probabilistic models can be derived by assuming appropriate distributions for the unobserved random variables. For example, assuming that they are independently and identically Gumbel distributed, the following multinomial logit model results:

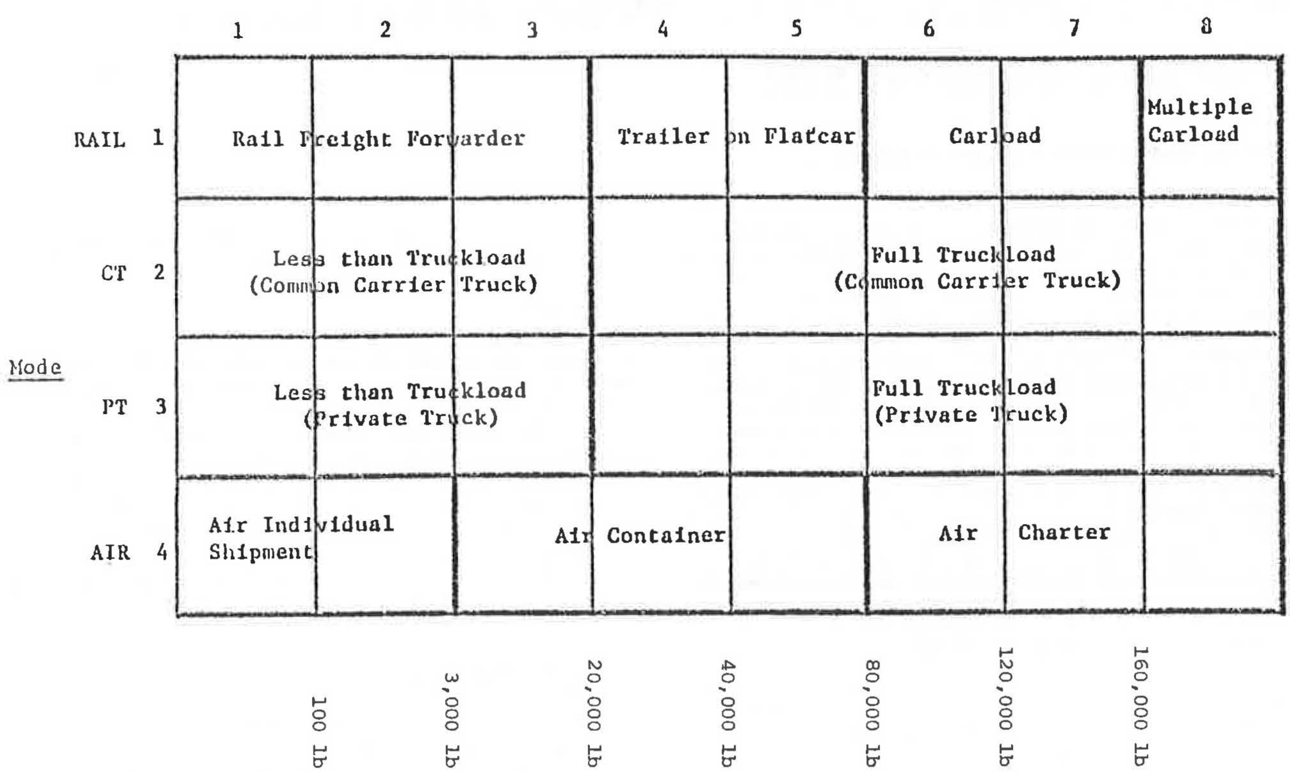
$$P_r(imq|A) = \exp(-\mu w_{imq}^{o}) / \sum_{i'm'q' \in A} \exp(-\mu w_{i'm'q'}^{o}) \quad (2)$$

where μ is the scale factor of a logit model. Models of this type can be referred to as random-cost models of short-run freight demand.

DEVELOPMENT OF DISAGGREGATE DATA BASE

To implement the model described here we used the 1972 Census of Transportation Commodity Transportation Survey (CTS) as the basic data base. We considered four modes and eight shipment-size categories. A mode and shipment-size combination represents an alternative transport service. The definition of choice alternatives is shown in Figure 1.

Figure 1. Definition of choice alternatives.



The data base was prepared by using the following procedures: (a) the records in the census are skimmed for records that are complete at the five-digit Standard Transportation Commodity Code (STCC) level; records for rail, common carrier truck, private truck, or air are chosen; (b) these records are extracted and expanded to produce the basic disaggregate data set; (c) a representative annual use rate is sampled for each shipment by using the procedures developed by Chiang and Roberts (8); (d) the unchosen alternatives that are to be considered for each shipment are chosen; and (e) transportation level-of-service attributes are developed for both chosen and unchosen alternatives.

The transportation level-of-service variables required in the model specification include freight rate and special charges, mean transit time, waiting time, transit-time reliability, loss and damage, and the time required to complete the investigation of loss and damage claims. We used a set of level-of-service models developed by the Massachusetts Institute of Technology (MIT) Freight Research Group, which have been documented by Roberts and Wang (9) and by Chiang and Roberts (10). The commodity attributes are taken from the commodity attribute file assembled at MIT from data obtained from a number of sources and documented by Kuttner (11).

SPECIFICATION OF LOGISTICS COST FUNCTION FOR JOINT-CHOICE MODEL OF MODE AND SHIPMENT SIZE

From inventory theory, the logistics cost faced by a receiver can be expressed as the sum of the order cost, transportation cost, capital carrying cost in transit, capital carrying cost in storage, stockout cost, etc., associated with a given logistics strategy. Assuming that there is no quantity discount in purchase, these cost components are the costs (disutilities) to be minimized in a joint choice model of mode and shipment size. The specification of these cost components as well as other variables are discussed as follows.

Transportation Charges

Transportation charges can be specified simply as $\beta_1(RATE_{imq} + SPC_{imq}) \cdot x$, where RATE is the freight rate, SPC is any special charges associated with the shipment such as pickup and delivery charges for trailer-on-flatcar service, and x is the annual use rate. The coefficient β_1 serves as a scaling factor.

Capital Carrying Cost in Storage

The average inventory level for nonsafety stock is assumed to be one-half of the shipment size. On the average, this amount of stock is held in storage for the time between orders. In practice, additional safety stock is held to protect against stockout (9). The amount of safety stock is assumed to be the reliability of transportation service in days multiplied by daily use rate of the commodity. Thus, capital carrying cost tied up in storage can be specified as $\beta_2 \cdot [(q/2) + R_{imq} \cdot u] \cdot P_1$, where reliability R is measured as transit time beyond the mean at a level of confidence of 90 percent, u is the daily use rate, q is the shipment size, and P is the purchase price of the commodity. Dividing β_2 by β_1 will produce an estimate of the implied interest rate.

Capital Carrying Cost in Transit

We specify two cost components--capital carrying cost during transit time and capital carrying cost from the time of arrival until a loss-and-damage claim is settled if loss and damage did occur. The specification is as follows:

$$\beta_n \cdot [(TT_{imq}/365) + (LDP_{imq} \cdot IT_m)/365] \cdot P_i \cdot x \quad (3)$$

where TT is mean transit time in days and LDP is the percentage of goods lost and damaged. IT is the time required to finish the investigation of a loss-and-damage claim and to pay the claim.

We have specified capital carrying cost in transit as two variables--one for emergency shipments (n = 3) and the other for regular shipments (n = 4). We define a shipment to be an emergency shipment if the annual use rate divided by the chosen shipment size is greater than 52; i.e., more than one order per week would be required if this shipment size were chosen regularly. Dividing $\beta_3(\beta_4)$ by β_1 will produce an estimate of the implied interest rate for these two types of shipments.

Order Cost

Order cost can be specified as β_5 $(P_i \cdot q)^{0.4} \cdot (x/q)$. This specification allows order cost to vary with the amount of a purchase, considering the fact that one is usually willing to spend more to process an order for a large purchase than for a small one.

Loss of Value During Transit or Storage

The loss of shelf life during transit or storage is important for time-sensitive goods such as newspapers and for perishable goods such as fruits and vegetables. We have specified this cost item as $\beta_6 \cdot [q - u(SHELF - TT_{imq} - WT_{imq})] \cdot P_i \cdot (1/q) \cdot x$, where SHELF is shelf life in days. The term $(SHELF - TT_{imq} - WT_{imq})$ is the time available to use the time-sensitive or perishable goods. Thus, $u \cdot (SHELF - TT_{imq} - WT_{imq})$ is the maximum shipment size for these goods if there is to be no loss due to spoilage or time loss of utility. The complete expression $\beta_6 \cdot [q - u \cdot (SHELF - TT_{imq} - WT_{imq})] \cdot P_i \cdot (1/q) \cdot x$ reports the loss of value associated with the shipment size q. The terms $(SHELF - TT_{imq} - WT_{imq})$ and $[q - u \cdot (SHELF - TT_{imq} - WT_{imq})]$ are restricted to be nonnegative.

Mode and Shipment Size Constants

Mode and shipment-size constants (β_7 to β_{22}) are specified to measure "pure-alternative" effects, i.e., the net effect of all attributes of an alternative not measured by other variables. The definitions of all variables are summarized in Table 1. All cost variables are specified as generic variables.

ESTIMATION RESULTS

The estimated results of the joint-choice model of mode and shipment size were performed by using maximum-likelihood procedures. By using the likelihood-ratio test, the hypothesis that all parameters are zero is significantly rejected.

The magnitudes of the coefficients should be interpreted relatively because the coefficients of the logit model are estimated as multipliers of the scale parameter μ. In order to draw economic inferences, we thus normalize the coefficients of all cost variables by the coefficient of TCOST. The results are shown below:

Variable	Normalized Coefficient
TCOST	1.0
CCCIS	0.571
CCCIT1 (emergency shipments)	45.783
CCCIT2 (regular shipments)	1.239
ODC	1.387
LOSSV	0.492

The normalized coefficient of CCCIS (0.571) gives the revealed preference on interest rate per year implied by the shipper's observed decisions. Note that the results are estimated to be significantly higher than the normal market cost of capital. The interest rate for capital carrying cost in transit for regular shipments is especially high (1.239), which indicates that shippers in the real world may have overemphasized the importance of transit time. This translates into a transit-time value of $0.003/day per dollar of value. This might also be explained by the uncertainty of transit time and the associated consequences of stocking out. The coefficient of CCCIT1 is estimated much higher than that of CCCIT2, which follows our expectations. Its normalized coefficient value of 45.783 translates into a transit time value of $0.125/day per dollar of value. For emergency shipments, travel time is obviously a major factor in the determination of modal choice.

Table 1. Definitions of variables for joint-choice model of mode and shipment size.

Parameter	Variable	Definition
β_1	TCOST	Transport rate and special charges
β_2	CCCIS	Capital carrying cost in storage
β_3	CCCIT1	Capital carrying cost in transit or tied up with a loss-and-damage claim for emergency shipment
β_4	CCCIT2	Capital carrying cost in transit or tied up with a loss-and-damage claim for regular shipment
β_5	ODC	Order cost
β_6	LOSSV	Loss of value during transit or storage
β_7 to β_{22}		Alternative dummy variables

SUMMARY AND CONCLUSIONS

This paper has shown only a very small part of what is rapidly becoming a powerful set of techniques for developing freight-flow information. This information could be of immense use to managers and policymakers for use in logistics planning, marketing, capital budgeting, and investment decisions. A disaggregate freight-demand model such as the one described here obviously occupies a key role among the available techniques, since it not only offers a way to resolve the modal-choice questions but it also begins to explain the underlying shipper behavior. Operational models such as this one are, however, only a first step, albeit an extremely important one, to successful application to real-world problems.

REFERENCES

1. A. Morton. A Statistical Sketch of Intercity Freight Demand. HRB, Highway Research Record 296, 1969, pp. 47-65.
2. J. Sloss. The Demand for Intercity Motor Freight Transport: A Macro-Economic Analysis. Journal of Business, Univ. of Chicago, Jan. 1971.
3. G. Wang and R. Epstein. Econometric Models of Aggregate Freight Transport Demand. Transportation Systems Center, U.S. Department of Transportation, Cambridge, MA, Working Paper WP-210-U1-81-A, 1975.
4. Studies on the Demand for Freight Transportation. Mathematica, Vol. 2, 1969.
5. E. Miller. Effect of Rates on the Demand for Railroad Services. Proc., Transportation Research Forum, 1972.

6. Y.S. Chiang. A Policy-Sensitive Model of Freight Demand. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, Ph.D. thesis, April 1979.
7. P. Roberts, M. Terziev, J. Kneafsey, L. Wilson, R. Samuelson, Y.S. Chiang, and C. Deephouse. Analysis of the Incremental Cost and Trade-Offs Between Energy Efficiency and Physical Distribution Effectiveness in Intercity Freight Markets. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, CTS Rept. 76-14, Nov. 1976.
8. Y.S. Chiang and P.O. Roberts. Representing Industry and Population Structure for Estimating Freight Flows. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, CTS Rept. 7608, Aug. 1976.
9. P. Roberts and K. Wang. Predicting Freight Transport Level of Service Attributes. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, CTS Rept. 79-17, Dec. 1979.
10. Y.S. Chiang and P.O. Roberts. A Note Describing an Empirically Determined Model of Transit Time and Reliability for Regular Route Trucking. Transportation Research, Part B: Methodological, Vol. 14B, No. 12, March/June 1980, pp. 59-65.
11. W.S. Kuttner. A Disaggregate File of Commodity Attributes. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, CTS Rept. 79-12, Aug. 1979.

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

Abridgment

Potential Demand for Passenger Rail Intercity Traffic and Possibility of Increasing Demand

WERNER BRÖG, WOLFGANG BLECHINGER, AND KLAUS HUBER

In the spring 1979, the Deutsche Bundesbahn (DB) (German Railroad Association) introduced a new system—Intercity (IC) 1979. Due to its innovations (average travel-time reduction by 20 percent, two-class train system, increased number of trains on a firm hourly schedule, and improved comfort), DB hoped to increase its number of potential passengers by inducing those who had previously used automobiles and airplanes to use the IC 1979 trains. The survey described here confirmed that this new concept would be successful. This was shown not only in the users' positive evaluations of the new system but also in the increased amount of travel (about 15 percent) on IC trains during the survey. Almost all the new passengers travel second class because of the deliberate change from exclusive IC trains to a fast, comfortable transportation mode for a broader spectrum of the population. An analysis of the potential increase in the number of passengers has proved the effectiveness of the new IC 1979 system.

Analysis of the entire market for intercity travel in the Federal Republic of Germany and the trend of the market in passenger rail travel in special segments of this market has shown basic changes in market potential and market structure in recent years. The percentage of trips for which individual transportation modes are used has consistently increased; it is now about 80 percent. In contrast to this, in 1975, for instance, passenger rail traffic accounted for only about 9 percent of the intercity traffic volume. In order to compete with cars and airplanes, it was of utmost importance for the Deutsche Bundesbahn (DB) (German Railroad Association) to improve the speed with which their trains traveled. The DB's market position could only be improved by catering to the most important customer demands. Thus, a thorough analysis of the total intercity passenger market and the development in demand for passenger rail traffic in the different market areas and intensive market research studies were performed prior to the institution of a new (two-class) train system.

The goal of the research was to show all the ways in which an improved offer could be adapted to market requirements and to extend the improvements to as much as possible. This meant that one needed to identify the criteria that determined choice of mode of transportation, to analyze these criteria, and then to classify them according to order of importance. The investigation identified the following factors as important for keeping current railroad patrons and substantially increasing the number of future railroad customers:

1. Travel time must be reduced,
2. Number of direct connections must be increased,
3. Trains must travel more frequently, and
4. Traveling must be made more comfortable.

For this purpose, DB introduced new and improved intercity (IC) 1979 trains on May 27, 1979, after a preliminary one-year test of this offer on the route from Hamburg to Cologne. Important characteristics of the new IC trains for passengers were introduction of the two-class system for all IC trains, increasing the speed of IC trains by 26 percent or 20 km/h as compared with that of the D-Züge trains, and a consistent hourly schedule. The results of these and other measures were to be studied in a market survey (1).

Four kinds of trains for intercity travel are mentioned repeatedly in this paper. These are the trans-European express (TEE) trains, which travel between the major cities of Europe, make relatively few stops, and only have first-class cars; IC trains, which are similar to TEE trains but travel only within Germany; and the new IC 1979 trains mentioned in this paper, which now have two classes--the D-Züge, a two-class express train that travels within Germany and is slower than the TEE and IC trains and makes more stops, and the Eilzüge, which has two classes and is used for short trips.

RESEARCH CONCEPT

In order to deal successfully with the primary goal

Table 1. Trip purpose.

Purpose	Total (%)	Travelers Who Used First Class (%)	Travelers Who Used Second Class (%)
Vacation	18	11	20
Personal	45	27	50
Business	27	58	19
Work and education	6	4	6
Armed forces personnel	4	-	5

Table 2. Response to survey of major improvements in IC 1979 train system.

Response	Mode: Train (%)	Airplane (%)	Car (%)	Total (%)
Improvements mentioned	55	42	36	39
Hourly train schedule	26[a]	27[a]	19[a]	21[a]
Second class	22	15	17	18
Faster transfers	19	12	9	10
Enlarged network	3	4	3	3
Comfort	5	4	2	3
Need for fewer transfers	1	0	1	1
IC surcharge	2	0	0	1
No improvements mentioned	18	16	14	14
Not familiar with IC system	19	38	37	35
No response	8	4	13	2

[a]Multiple answers.

Table 3. Perception of IC 1979 system.

Response	Travelers Who Used First Class (%)	Travelers Who Used Second Class (%)	Total (%)
Advantages	53	62	60
Travel-time reduction	38[a]	50[a]	48[a]
Hourly schedule	15	6	8
Comfort	7	6	6
Second class	4	6	6
Less expense	1	3	2
Other	1	1	1
Disadvantages	7	4	5
IC surcharge	0[a]	2[a]	2[a]
Short-distance train disturbances	3	1	2
Second class	2	-	0
Other	3	1	1
One system as good as other	15	12	13
No opinion	25	22	22

[a]Multiple answers.

of the investigation, i.e., the current or likely quantitative and qualitative effects of the introduction of IC 1979 trains on railway traffic, it was necessary to interview actual users, i.e., persons who used the IC trains; to interview persons who traveled via car and airplane on routes covered by the IC trains; and to interview particular subsections of these groups intensively.

For these reasons, a three-step research concept was used:

1. A written survey of about 3000 passengers, most of whom were traveling on the IC trains;
2. A written mailback survey of about 2000 persons traveling between cities by railroad, car, or airplane on IC routes; and
3. Personal, in-depth interviews of 200 persons traveling between cities via railroad, car, or airplane on IC routes.

TRAVEL CHARACTERISTICS OF IC USERS

Travelers

The train-user survey showed that trip purpose was considerably different for persons traveling in the different classes of the new IC trains. There were twice as many persons on vacation trips in the second class as in the first class, whereas only about one-quarter of the second-class travelers were making business trips.

Through the introduction of this second class (previously, in IC trains, one could only travel first class), the train system structure was changed. This has had effects (described later) on the evaluation of the offer by passengers as well as on the passengers' resulting demands. The IC system, which was previously somewhat exclusive, has now become available to a wide spectrum of travelers (Table 1).

Trip Pattern

Only a third of all IC passengers reach their destinations without having to transfer to another train or trains. The remainder travel on an average of 1.5 additional trains, so that, on the average, almost every IC passenger has to transfer to another train. Most of the passengers use D-Züge trains to get to and from IC railroad stations. Passenger rail traffic on intercity stretches outside the IC network now tends to use the quicker and more comfortable IC connections whenever this is possible. This trend should be taken advantage of by encouraging and improving the transfer trains, such as the D-Züge and the Eilzüge. It does not suffice only to make transferring between IC trains less problematical and more comfortable, as had already been done at IC railroad junctions since the IC 1979 trains were introduced.

EFFECT AND EVALUATION OF IC 1979 TRAINS

Estimation of IC Potential

In estimating the potential demand, one is confronted with the basic problem that before the IC 1979 system was introduced on a national scale, it had been tested on the Hamburg-Cologne route and that these trains had been used by a number of the persons interviewed in the survey now being discussed. Therefore, the estimated change in potential demand can be seen in relation to two conditions--the situation prior to the test route and the situation prior to the national introduction of the IC 1979 trains.

In order to further clarify this problem, the percentage of passengers (statistics were supplied by DB) that had already used the IC trains on the test route was determined. For this group of persons, travel behavior prior to the institution of the IC route was estimated by using a mathematical computation under ceteris paribus conditions. The sum of the two values shows travel behavior prior to the introduction of IC 1979 trains (Tables 2 and 3).

According to this, one-third of the passengers who used IC 1979 trains had traveled with the IC and TEE trains during the previous year; approximately every second passenger had used a D-Züge train; every seventh passenger was induced to change mode or to make an additional trip due to the special offer. Also, the number of passengers who traveled on IC trains tripled, although four-fifths of this increased travel volume was caused by trips made on IC trains instead of on D-Züge trains. Most of the passengers who had previously traveled on D-Züge trains used the second class; only every 20th person traveled first class. For other passengers, every 10th passenger used the first class.

In order to determine how many more persons were induced to use trains due to the introduction of the IC 1979 system, those persons had to be surveyed who had not previously used trains. Persons who had switched from D-Züge trains or other trains to the IC 1979 trains were not included. According to this survey, up to the fall of 1979, 13.7 percent more persons traveled by train due to the introduction of the IC 1979 system. Two out of three of the additional passengers had switched from the automobile to the train. Moreover, approximately every 15th passenger had already used an IC train on the test route. If one determines the probable behavior of these persons prior to the introduction of the test route, an additional potential of approximately 1.2 percent results. This means that the increased travel generated by the new system is about 14-16 percent in this estimation.

At the same time, the introduction of IC 1979 trains gave passengers the option of choosing between two classes. Those who changed the class in which they traveled could be divided into four groups:

1. Passengers who had previously used IC trains and will continue to do so but will travel second class instead of first class,
2. Passengers who had previously traveled first class on the D-Züge trains and now travel second class on the IC trains,
3. Passengers who had traveled second class on the test route but had previously traveled on IC trains and therefore first class, and
4. Passengers who had traveled second class on the test route but had previously traveled first class on the D-Züge trains.

In this estimation, the largest group that switched from one class to another was considered, i.e., those who changed classes for any of the train connections. The number who changed classes was thus as follows (Tables 2 and 3):

1. For those who used the IC trains, about 11.8 percent since the introduction of the test route and about 12.9 percent prior to that;
2. For those who had traveled on D-Züge trains, about 13.9 percent since the introduction of the test route and about 15.2 percent before that.

Therefore, the percentage of those who switched classes was again about 14-16 percent for this survey.

Structure of Those Who Switched Classes and of Increased Demand

A classification of those who changed classes according to trip purpose shows that their structure is, for the most part, similar to that of those who came to use the IC 1979 trains in a different manner and immediately traveled second class. In contrast to those who changed classes, the trip purposes of the additional train passengers differ little from the hitherto existing potential. All in all, one can see that, in contrast to those who switched classes, the major impact is not on those traveling for private reasons but rather on those who were on official or business trips and especially for armed forces personnel (Table 3).

Evaluation of IC 1979 Trains

In addition to the two most important features of the IC system--the hourly train schedule and the two-class system--a number of other changes were introduced. For the most part, these changes were meant as orientation aids for passengers. The loudspeaker announcements in the trains were especially welcome as were the standardized car descriptions and the platform designations in color. The passenger's option of a free seat reservation is apparently not well enough known but can be evaluated

Figure 1. Changes in travel demand.

Used prior to introduction of IC '79	Total number of passengers (%)	Percentage travelling: first class (%)	Percentage travelling: second class (%)	Test route: Total number of passengers (%)	Test route: first class (%)	Test route: second class (%)
Standard IC/TEE trains	25.2 +)	14.1 +)	11.1 +)	2.4 +)	1.3 +)	1.1 +)
IC on the test route	8.4 ++)	1.7 ++)	6.7 ++)			
1st class	2.4	1.7	0.7			
2nd class	6.0	-	6.0			
D-Zug	52.7	2.6	50.1	4.8	0.2	4.6
1st class	3.9	1.8	2.1	0.3	0.1	0.2
2nd class	48.8	0.8	48.0	4.5	0.1	4.4
(at night)	(4.6)	(0.4)	(4.2)	(0.4)	(0.0)	(0.4)
Car	9.1	0.9	8.2	0.8	0.1	0.7
Plane	2.0	0.4	1.6	0.2	0.1	0.1
Trip not taken	2.6	0.3	2.3	0.2	0.0	0.2
	100.0	20.0	80.0	8.4	1.7	6.7

+) The sum of the latter two columns is the figure given in the total

++) Mathematical classification of passengers on the test route

Figure 2. Increase in travel demand and changes in class.

Increased travel

Used prior to introduction of IC '79	Total number of passengers %	Percentage travelling first class %	Percentage travelling second class %	Test route: Total number of passengers %	Test route: Percentage travelling first class %	Test route: Percentage travelling second class %	Test route: Total travel increase
Car	9.1+)	0.9+)	8.2+)	0.8+)	0.1+)	0.7+)	
Plane	2.0	0.4	1.6	0.2	0.1	0.1	
Trip not taken	2.6	0.3	2.3	0.2	0.0	0.2	
	13.7	1.6	12.1	1.2	0.2	1.0	14.9

Persons who switched classes

Used prior to introduction of IC '79		Test route	Total number of persons who change classes
Standard IC/TEE	11.1+)	1.1+)	
IC on the test route 1st class	0.7	-	
D-Zug 1st class	2.4	0.2	
	13.9	1.3	15.2

+) The sum of the latter two columns is the figure given in the total

as a positive change. There is also a positive response to the air conditioning installed in the cars, including some of the second-class cars (2).

On the negative side, passengers who had used the dining cars frequently criticized them, especially the "Quick-Pick", or self-service, restaurant. First-class passengers were particularly critical.

The best known of the IC system's improvements are the hourly schedule, the fact that one can travel second class, and, with certain exceptions, the fact that these trains are faster. The order of preference for these changes is the same for persons who usually travel by airplane, train, or automobile. The slogan "every hour on the hour" has been successfully propagated (Figure 1). Two-thirds of the actual users have a positive attitude toward the new system. By far the most important improvement is deemed to be the reduced travel time, whereas the hourly schedule is important only for first-class passengers, most of whom are making business trips (Figure 2). Thus, "every hour on the hour" was effective as a public-relations slogan, but for most of the actual users, it was of secondary importance. For them, it was more important to travel inexpensively and as directly as possible with better connections and therefore more quickly (3).

REFERENCES

1. H. Adler. Ein Jahr Intercity--jede Stude, jede Klasse. Die Bundesbahn, Vol. 6, June 1980, pp. 385-387.
2. Socialdata (Institute for Empirical Social Research). Auswirkungen des neuen Reiseangebotes IC '79 auf die Nachfrage im Schienenpersonenverkehr. German Railroad Association, Mainz, Federal Republic of Germany, Dec. 1979.
3. Socialdata (Institute for Empirical Social Research). Auswirkungen des neuen Reiseangebotes IC '79 auf die Nachfrage im Schienenpersonenverkehr. German Railroad Association, Mainz, Federal Republic of Germany, Final Rept., June 1980.

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

Abridgment

Estimating Vehicle Weight Distribution Shifts Resulting From Changes in Size and Weight Laws

CHIEN-PEI YU AND C. MICHAEL WALTON

Vehicle-weight-shifting methodology is an important element in the economic analysis model for changes in vehicle size and weight limits. The existing models were analyzed based on data for truck weights gathered in Texas since 1954. Results of the analysis show that the pattern of vehicle weight redistribution varies with vehicle class, which suggests that each vehicle class be considered separately. The historical and current use patterns of each vehicle type, practical maximum gross vehicle weight, and equipment-replacement policies should all be considered in a forecast. The phenomena described by the demand and volume-constraint concepts were observed in three vehicle types. Steering-axle weight distribution was not affected by the 1975 change in the Texas weight law, which allowed gross vehicle weight to increase from 72 000 to 80 000 lb, tandem-axle weight from 32 000 to 34 000 lb, and single-axle weight from 18 000 to 20 000 lb. The assumption that the distribution in axle weights for each type of axle has the same ratio to gross weight was found to be basically sound. The analyses of distribution of multiplying factors reveal large discrepancies and the need for further investigation. The findings suggest that further study is warranted to produce a more-accurate methodology for forecasting vehicle weight distribution under any proposed size and weight limits.

In evaluating the effects of the changes of motor vehicle size and weight limits on vehicle operating cost, fuel consumption, and highway maintenance and rehabilitation cost, one key element is the shift in vehicle weight distribution. In several previous studies on the economic effects of changes in size and weight limits, four methods were proposed to forecast the shifted vehicle weight distribution. These methods can be summarized as follows:

1. First Federal Highway Administration (FHWA) methodology: The methodology, presented in the Manual of Procedures for Conducting Studies of the Desirable Limits of Dimensions and Weights of Motor Vehicles (1), estimates axle weight distribution from data collected in states that have limits similar to those under investigation.
2. Second FHWA methodology: This methodology, also presented in the same report (1), is a step-by-step procedure used to predict vehicle weight distribution under the proposed size and weight limits from existing weight distribution.
3. The National Cooperative Highway Research Program (NCHRP) methodology: This is an improved and expanded version of the second FHWA methodology and is published in NCHRP Report 141 (2).
4. The Texas State Department of Highways and Public Transportation (SDHPT) methodology: This was developed during the Texas study on the effects of heavier trucks on highways (3). It is conceptually an improved version of the NCHRP methodology.

During the initial phase of the Texas truck weight study, both the first and the second FHWA methodologies were examined. The first methodology was found to be inadequate since it relied on data from states that had size and weight limits similar to proposed changes in the state in question. The compatibility of data and circumstances can vary significantly from state to state, which makes such great assumptions difficult. The second FHWA methodology is the predecessor of the NCHRP methodology; therefore, the second FHWA methodology was rejected in favor of the NCHRP methodology.

NCHRP SHIFTING METHODOLOGY

The NCHRP shifting procedure contains two parts: the first calculates the gross vehicle weight (GVW) distribution of each vehicle class under the current and the proposed limits, and the second calculates the axle weight distribution of each vehicle class under the current and the proposed limits. Both parts are essential to the overall computation of benefits and costs. Distribution of GVW is directly related to the calculation of vehicle operating cost, fuel consumption, and payload carried. Distribution of axle weight is needed for the estimation of the total number of 18-kip single axles to be expected. The NCHRP shifting procedure contains the following explicit assumptions (2):

1. Given an increase in legal weights, the empty weight of the trucks will increase to provide for the strength and durability of the vehicle in use under heavier payloads.
2. Trucks will carry increased payloads per trip and therefore operate with increased axle and gross weights.
3. Vehicle weight distribution will change from the current legal limits to future limits as a function of the change in practical maximum gross vehicle weight (PMGVW) of each vehicle class. PMGVW has been defined as the sum of the individual axle legal weights; the front or steering-axle weights are set at a reasonable amount consistent with that class of vehicle as indicated through roadside weighting.
4. Under the new legal limits, the change in axle weight distribution will generally be consistent with the increase to gross weight. The new distribution in axle weight for each type of axle is assumed to retain the same gross-weight ratio under the new limits as was found with roadside weightings under the current limits.

The pattern of shift of the NCHRP shifting-procedure model is based on past research, which indicates that with an increase in GVW limit or axle weight limit, the gross weight distribution will experience a shift to the right, as shown in Figure 1 (4). However, this model was based on 1962 truck weight study data and does not apply to more-recent size and weight situations.

The type of shift that was described in NCHRP Report 141 can be represented by Figure 2. Each weight interval of the current limit is adjusted by a multiplier to represent the weight interval under the proposed limit. The multiplying factor is assumed to be unity at the lowest gross weight interval and increases linearly until it reaches the practical maximum gross at the current limit, beyond which the factor remains constant and equals the ratio of PMGVW at the proposed limit over PMGVW at the current limit.

SDHPT SHIFTING METHODOLOGY

After the NCHRP shifting procedure had been reviewed, the following recommendations were made: (a)

Figure 1. Typical historical shifts in gross weight distribution.

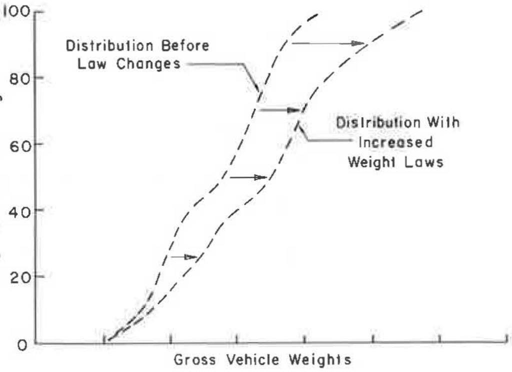
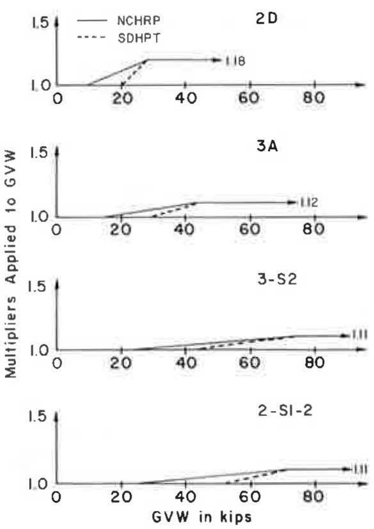


Figure 2. Multiplying factors used by NCHRP and SDHPT methodologies in forecasting vehicle weight distribution shift due to 1975 weight-law change.



that a computerized curve-fitting and curve-smoothing procedure be used, (b) that no substantial increase in empty vehicle weights be expected, and (c) that the procedure account for the fact that volume- and demand-constrained vehicles (vehicles that carry low-density cargo or less-than-trailer-load capacity) will not be much affected by the increase in weight limits. This was determined by allowing the upper range of the weight intervals to experience a more-substantial shift than the lower range (4).

These recommendations were incorporated into the SDHPT model, which varies from the NCHRP model in the following major areas:

1. The empty weight of the vehicle is assumed to be the same regardless of a change in size and weight limits.
2. A computerized curve-smoothing and curve-fitting procedure is used.
3. More of the heavily loaded vehicle trips are assumed to shift to a larger GVW in proportion to the ratio of future PMGVW limit to current PMGVW limit.
4. Lightly loaded vehicles are assumed to be unaffected by the change in the law (3).
5. Rather than keeping the number of vehicles constant and varying the payload, the SDHPT procedure holds the payload constant regardless of the weight limit.
6. The NCHRP procedure uses both GVW and axle weight distribution to compute the final costs and benefits, whereas the SDHPT procedure eliminates the calculation of axle weight distribution in an effort to further streamline the procedure.

The differences cited in items 3 and 4 above are reflected in the multiplying factors used.

Research done during the initial phase of the Texas truck-weight study recommended that the multiplying factors for 2D and 3A start increasing from 50 percent of the cumulative percentage of GVW, whereas 3-S2 and 2-S1-2 start increasing from 33 percent. It was also found that distributing the non-front-axle weight portion of GVW evenly among those axle groups does not affect the outcome significantly.

ADEQUACY OF EXISTING METHODOLOGIES

The SDHPT procedure was developed by using pre-1975 data. Since 1975, significant events that affect truck size and weight limits and operational aspects of the motor carrier industry have occurred; therefore, more-recent (or post-1975) data could provide valuable insight into the vehicle weight redistribution process. At the time the procedure was developed, there was little supporting evidence for the volume- and demand-constraint concepts or for the assumption that only those vehicles that operate near their current weight capacity would shift to higher GVW once the weight limit was increased (4).

In spring 1980, the Texas truck-weight survey data for the years 1976 and 1978 were made available. In an effort to update the data base and to validate the benefit-cost analysis methodology, a number of sample runs were made to compare the model's outputs based on pre-1975 data and post-1975 data. In the process, the need for additional refining of the current shifting methodology became apparent; hence, a number of analytical programs were developed to compare data with the projections based on the current weight-shifting methodology. Truck-weight data for Texas from 1954 were also plotted in an effort to gain insight into the weight redistribution process. The data were arranged in variety of ways and compared. These results indicated the following:

1. The historical-shift pattern shown in Figure 1 was not observed in the cumulative frequency plots for most vehicle types (see Figure 3--NCHRP and SDHPT plots represent their predictions of GVW distribution after 1975 weight-law change).
2. The change in the Texas weight limit in 1975 (single axle from 18 000 to 20 000 lb, tandem axle from 32 000 to 34 000 lb, and GVW from 72 000 to 80 000 lb) did not affect the steering-axle weight distribution.
3. What SDHPT methodology described as the volume- and demand-constraint concepts were more evident in three vehicle types (2D, 3A, and 2-S1-2) than in the fourth (3-S2).
4. The NCHRP model's assumption that "the new distribution in the axle weight for each type of axle may be assumed to retain the same ratio to gross weight under the new limit as was found in the roadside weighing" has merit and is reasonable.
5. The assumption in current methodolgies that truck weights will shift in proportion to the ratio of the proposed PMGVW limits to the current PMGVW limit is challenged. Figure 4 shows the multipliers computed from actual data. In comparing Figure 2 with Figure 4, a large discrepancy is noted. The

Figure 3. GVW distribution based on truck weight survey and on predictions made according to NCHRP AND SDHPT methodologies.

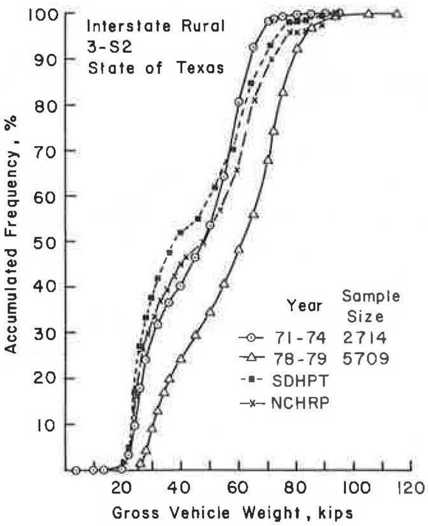
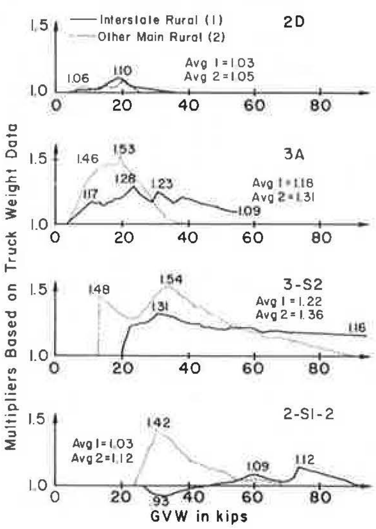


Figure 4. Multiplying factors based on truck-weight survey.



cause for such a discrepancy is not fully understood.

6. The historical and current use patterns of PMGVW under the proposed limit compared with those of PMGVW under the existing limit indicate that the redistribution of vehicle weight due to changes in size and weight laws varies from one vehicle class to another. Tire construction, trailer type, and terminal requirements must also be considered.

A vehicle-type-based methodology that allows consideration of the above-mentioned factors is preferred to a general one.

CONTINUING MODELING EFFORT

Based on the above observations, it was concluded that a more-accurate method of forecasting vehicle weight distribution for any given or proposed size and weight limit should be explored. There were three possibilities: (a) modify the SDHPT procedure, (b) approach the redistribution problem by developing axle-weight relationships rather than GVW, or (c) combine the GVW procedure for single-axle vehicles (2D and 2-S1-2) and the axle-weight procedure for vehicles that have tandem axles (i.e., 3A and 3-S2).

It may be possible to better understand the weight-redistribution process from an analysis of axle weights for certain vehicle types, particularly those that have tandem axles. Weight data from axle groups can be combined to obtain gross vehicle distribution for the estimation of vehicle operating cost and fuel consumption as in the current procedure.

CONCLUSION

The vehicle weight redistribution process under the new size and weight limits remains an important issue in the estimation of any resultant effects. Past methodologies--from the FHWA methodology and the NCHRP methodology to the latest SDHPT methodology--have all contributed to a better understanding of the redistribution process. However, the availability of more-recent data, particularly since the last change in vehicle weight limits in Texas as in many other states, has made the validation of these procedures necessary. The findings have confirmed some of the assumptions in the existing methodologies and have challenged a number of other assumptions. It is hoped that continuing research in this area will produce a methodology that can more accurately forecast vehicle weight distribution behavior under any proposed change in motor vehicle size and weight limits.

ACKNOWLEDGMENT

This study was performed at the Center for Transportation Research at the University of Texas at Austin. We wish to thank the sponsor, the Texas SDHPT, and the highly qualified staff at the center.

This report reflects our views and we are responsible for the contents, facts, and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Texas SDHPT. This report does not constitute a standard, specification, or regulation.

REFERENCES

1. R. Winfrey and others. Manual of Procedures for Conducting Studies of the Desirable Limit of Dimensions and Weights of Motor Vehicles. FHWA, U.S. Department of Transportation, Rept. FHWA-RD-73-68, July 1970.
2. R.E. Whiteside, T.Y. Chu, J.C. Cosby, R.L. Whitaker, and R. Winfrey. Changes in Legal Vehicle Weights and Dimensions: Some Economic Effects on Highways. NCHRP Rept. 141, 1973.
3. C.M. Walton, J.L. Brown, and D. Burke. Heavy Trucks on Texas Highways: An Economic Evaluation. TRB, Transportation Research Record 725, 1979, pp. 8-15.
4. J.G. Larkin. Modeling Future Truck Weight Patterns as Influenced by Alternative Vehicles Weight Legislation. Univ. of Texas at Austin, master's thesis, 1978.

Publication of this paper sponsored by Task Force on Motor Vehicle Size and Weight.