INVESTMENT EVALUATION MODEL FOR MULTIMODAL TRANSPORT CORRIDORS

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A method of economic evaluation of centrally focused multimodal urban transport corridors is presented that is based on certain production theory principles. Production functions are developed in terms of average door-to-door travel velocity in a corridor as a function of commuter-rail and expressway-facility inputs. Cost data are used to establish the optimum combinations of transport mode inputs for various travel speeds. The information used to develop the relationships was obtained in the Toronto region. The use of the techniques described in the paper allows the technical and economic characteristics of the modes to be examined in a quasi-continuous way, which allows a broad range of potential modal combinations to be evaluated. This is in contrast to the normal economic evaluation approach, which chooses from among a set of mutually exclusive, mode-specific alternatives that may not include the optimal alternative. The framework allows the examination of a range of policy variables such as parking charge changes in the central business district and the effect of dial-a-bus as a residential feeder mode.

•MUCH has been written in transport planning literature about the need for urban transport systems that have a balance between public transport and highway-oriented systems. However, an evaluation technique does not exist that allows this notion of balance to be identified objectively. A variety of urban transport economic evaluation techniques have been directed toward the evaluation of single-mode, mutually exclusive, transport-investment projects (1, 2, 3).

In most medium-to-large urban areas, travel within transport corridors is provided by a mixture of complementary transport modes. Rahman and Davidson (4) have proposed a technique for evaluating a transport system consisting of road and bus transit facilities, and they have applied this technique in a general way to transport investment evaluation in Brisbane, Australia. This technique is based on certain principles of the theory of production of microeconomic theory. There are difficulties with the way in which urban transport as a productive process has been conceptualized by Rahman and Davidson (4).

This paper describes a method of economic evaluation for multimodal transport corridors that also is based on the theory of production. The method of evaluation advanced in this paper is illustrated by a slightly idealized example of a typical radial transport corridor within the Toronto region.

URBAN TRANSPORT CORRIDOR

Figure 1 shows an idealized urban transport corridor that is typical of certain radial corridors within the Toronto region. In the corridor illustrated, 2 suburban areas are

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located 15 and 25 miles (24 and 40 km) from the central business district along a radial corridor. These 2 communities are to be connected to the central business district by some combination of road and public transport facilities.

Table 1 gives data on the commuter travel demands expected along this corridor throughout the day. The peak-hour demand from each community is 6,000 trips, and it is assumed that 5 peak hours are in each day, which yields 30,000 peak-period trips from each community. It is assumed as well that there are 30,000 off-peak-period trips per day, which yields a total daily person-trip demand of 120,000 trips.

The corridor characteristics presented in Figure 1 and Table 1 are similar to the characteristics of corridors in the Toronto region within which commuter-rail services have been established or are contemplated. Actual demand characteristics have been idealized, and the number of communities served has been reduced to 2.

In the example discussed in this paper, the only 2 modes of transport considered for the corridor are a commuter-rail facility and an expressway. Bus transit options have been analyzed by using the techniques discussed in this paper, but these options are discussed elsewhere (5).

Certain assumptions were made in the analysis described in this paper.

1. No existing expressway or commuter-rail facilities are in the corridor.
2. The facilities will be located equally in urban and rural areas where land market prices are \$50,000 and \$2,000/acre (\$125,000 and \$5,000/hm^2) respectively; all other costs are in 1969 prices.
3. The discount rate is 8 percent/year.
4. All trains in the peak hour have 10 coaches.

TRANSPORT MODE COST FUNCTIONS

Total annual costs for several transport modes have been calculated by using typical cost data for the Toronto region (5). The input quantities of the 2 transport modes were characterized by the following units:

1. Number of expressway lanes in 1 direction for highway facilities and
2. Number of trains per hour in 1 direction for commuter-rail facilities.

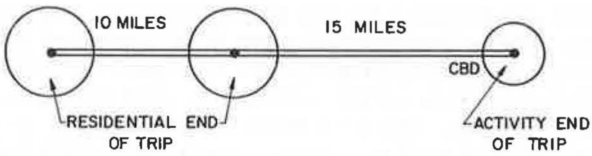
Costs included in the transport mode cost functions were costs associated with providing the corridor facilities and services (agency resource costs) and nonperceived costs of using the facilities and services for automobiles. Several or all of the following cost components, depending on the mode analyzed, were included in the agency resource cost element of the total cost function:

1. Land acquisition,
2. Traveled way and structures,
3. Rolling stock,
4. Parking facilities,
5. Maintenance,
6. Operation, and
7. Overhead and administration.

The second element included in the total cost function is nonperceived user cost of automobile operation. Half of these annual costs were assigned to corridor trip making and were divided by 1.3 to account for an estimated car occupancy rate. The components of these nonperceived user costs are capital and fixed costs of car ownership and nonmarginal costs of car operation.

A detailed description of the derivation of the transport mode cost functions is presented elsewhere (5). Tables 2, 3, and 4 give a summary of the total annual costs per mile (kilometer) of the various types of transport facilities analyzed. Figures 2 and 3 show a summary of cost functions for automobile and commuter-rail modes as

Figure 1. Radial transport corridor characteristics.



Note: 1 mile = 1.6 km.

Table 1. Summary of corridor demand characteristics.

	Number of Person Trips, All Purposes		
Time Period	Community A CBD	Community B CBD	Total
Peak hour	6,000	6,000	12,000
Peak period[a]	30,000	30,000	60,000
Off peak	30,000	30,000	60,000
Daily[b]	60,000	60,000	120,000

[a]Assuming 5 peak hours in a day.
[b]Total daily trips = 10 times the number of peak-hour trips. Daily peak-period trips/daily non-peak-period trips = 1.0.

Table 2. Total annual automobile costs per mile (kilometer).

Lanes in 1 Direction	Costs (dollars)	Lanes in 1 Direction	Costs (dollars)
2	309,000	7	496,000
3	340,000	8	523,000
4	369,000	9	541,000
5	399,000	10	577,000
6	471,000		

Note: $1/mile = $0.62/km.

Table 3. Total annual bus costs per mile (kilometer).

Buses per Hour in 1 Direction	Costs (dollars)		
	Busway	Exclusive Lane	Mixed Traffic
20	193,000	93,000	27,000
40	200,000	100,000	37,000
80	215,000	115,000	56,000
120	231,000	132,000	78,000
160	246,000	146,000	97,000
200	261,000	161,000	117,000
240	277,000	178,000	137,000
320	308,000	208,000	178,000
400	346,000	248,000	226,000

Note: $1/mile = $0.62/km.

Table 4. Total annual rail costs per mile (kilometer).

Trains per Hour in 1 Direction	Costs (dollars)	Trains per Hour in 1 Direction	Costs (dollars)
2	223,000	12	432,000
4	258,000	14	453,000
6	306,000	16	476,000
8	339,000	18	540,000
10	401,000	20	558,000

Note: $1/mile = $0.62/km.

Figure 2. Facility cost functions for commuter-rail facilities.

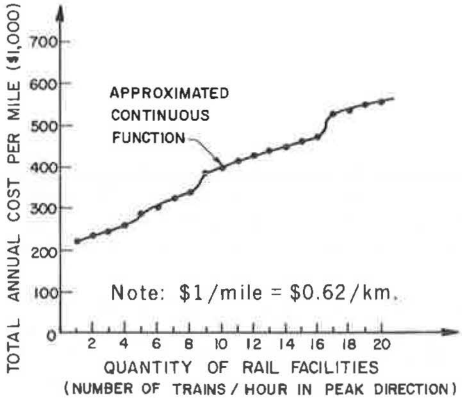
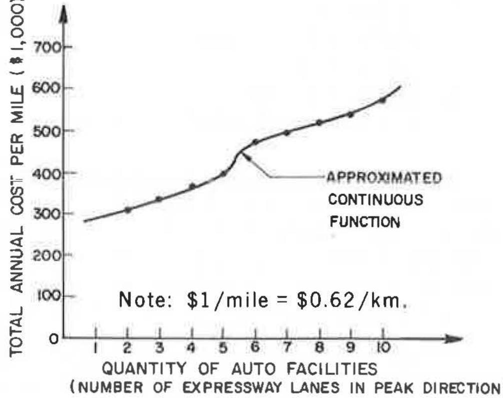


Figure 3. Facility cost functions for automobile facilities.



continuous functions. These functions are, in reality, step functions.

TRANSPORT MODE ISOCOST CURVES

Table 5 gives the combinations of automobile and commuter-rail facilities that can be supplied for $800, 000 per year. Similar isocost tables could be constructed for other equivalent annual investments. Figure 4 shows the family of isocost curves developed for the corridor shown in Figure 1. The irregularities in these isocost curves are a reflection of the discreteness of transport investment. The isocost curves are shown as continuous functions in Figure 4 even though feasible combinations of the 2 transport modes exist only at a specific number of supply conditions.

Although the cost functions shown in Figure 4 are not linear, the average unit cost of the expressway facilities is about $33,000/lane/mile ($20,500/lane/km). The average unit cost of the commuter-rail facilities is about $18,000/train/hr/mile ($11,200/train/h/km).

TRANSPORT CORRIDOR PRODUCTION ISOQUANTS

Transport corridors function by combining the capabilities of various transport modes to provide transport service for the demand expected in the corridor. Various combinations of transport modes may be used in a corridor to produce various levels of transport service. This process of producing transport service in a corridor may be described in terms of an economic concept called a production isoquant. A production isoquant is simply a function showing all combinations of inputs technically capable of producing a given level of output.

The level of transport service provided in the corridor has been described in terms of the average speed of travel of all users within the corridor. Thus the transport production isoquants are described in terms of various average travel speeds. Figure 5 shows the sequence of activities followed to establish the production isoquants.

Points on the production isoquant graph are obtained by postulating a specific combination of transport modes and then calculating the average speed of travel in the corridor. An initial estimate of the modal split in the corridor was made, and the transport demand given in Table 1 was allocated between the 2 modes. The user-perceived travel costs for each transport mode were estimated by using the generalized travel cost concept. These line-haul costs then were added to the costs incurred at the residential and employment ends of the trips. Table 6 gives the generalized travel cost formulas used.

Figure 5 shows that a 2-stage modal-split model was used to allocate the travel demands between the modes. A constant number of captive transit riders were identified and a logit-modal-split model that uses generalized travel cost differences was used to estimate the split of choice riders. The modal split estimated initially was then compared with the calculated modal split, and the process was reiterated until a stable modal split was obtained. This iterative sequence is necessary because travel time on each mode is a function of the patronage of that mode. Calculation of the equilibrium modal-split proportion then allows average corridor velocity of all trip makers to be estimated, and this provides 1 point on the production isoquant.

Figure 6 shows the isoquant curves developed for the commuter-rail and freeway corridor for a range of average corridor travel speeds from 23 to 50 mph (37 to 80 km/h). The points calculated by the analysis sequence shown in Figure 5 are shown in Figure 6.

For a specific average speed, a production isoquant in Figure 6 shows the marginal rate of substitution of rail facilities for road facilities. The isoquants shown in Figure 6 indicate that, as the input of each mode increases, the marginal productivities of the modes decrease. The initial increases in the supply of either mode produce larger increases in the average corridor velocity than subsequent increases do.

Table 5. Mode combinations obtainable with $800,000 annual investment.

Freeway Lanes	Annual Investment (dollars)		Trains per Hour
	Automobile	Rail	
2	309,000	491,000	16
3	340,000	460,000	14
4	369,000	431,000	11
5	399,000	401,000	10
6	471,000	329,000	7
7	496,000	304,000	5
8	523,000	277,000	4
9	541,000	259,000	4
10	577,000	223,000	1

Table 6. Generalized travel cost formulas.

Mode	Trip Distance (miles)	Cost Plus Time Formula (dollars)
Automobile	15	$1.85 + 0.02^a$
Automobile	25	$2.16 + 0.02^a$
Rail	15	$1.68 + 0.02^a + \frac{0.05^b}{2}$
Rail	25	$2.13 + 0.02^a + \frac{0.05^b}{2}$

Note: 1 mile = 1.6 km.

[a]Correction time factor. [b]Rail headway factor.

Figure 4. Isocost curves for a rail-automobile corridor.

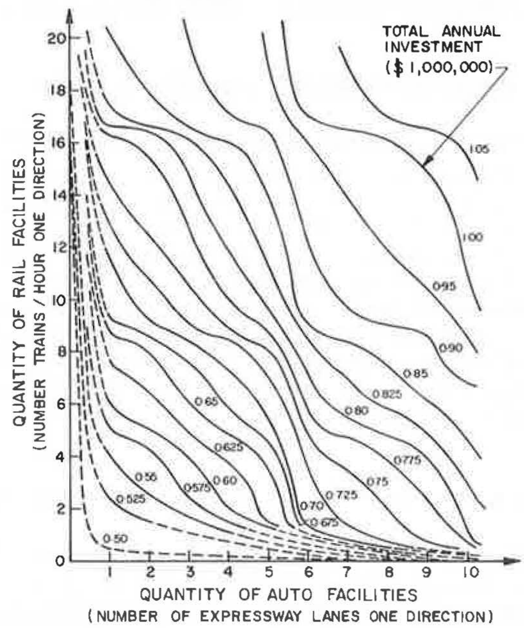
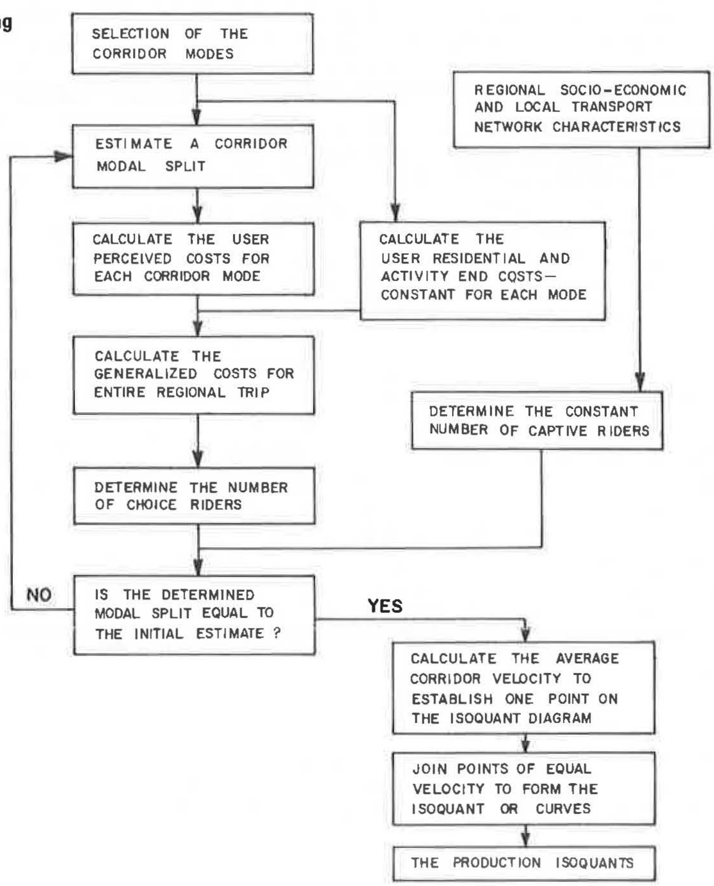


Figure 5. Process for calculating isoquant functions.



Figures 7 and 8 show the change in marginal productivity of both modes for 2 levels of input. These figures demonstrate clearly the decreasing marginal productivities of the 2 modes. In 1 case shown in Figure 7, there is an initial increase in the marginal productivity of the commuter-rail service. This figure also demonstrates that the marginal productivity of the modes is smaller when the supply of the second mode is higher, which is not an unexpected result. For example, unit changes in the number of commuter-rail trains per hour are much more effective when only 3 expressway lanes are supplied than when 4 expressway lanes are supplied. Similar comments may be made about the marginal productivities of the expressway lanes, which are shown in Figure 8.

The slope of the transport corridor isoquant curves is a reflection of the technological characteristics of the 2 transport modes and the modal-split behavior of passengers. For the commuter-rail mode, the initial increments in the level of train service (up to the point at which supplied seat capacity equals seat demand) serve to relieve highway congestion and shorten train headways. Therefore, marginal productivities increase. When 5 trains run per hour and 3 expressway lanes are supplied, unit increases in the train level of service will only decrease the train headways. Further increases in the rail service have a diminishing marginal effect on rail patronage because fewer people are diverted from the car mode. Furthermore, expressway speed is increased only slightly, and overall average corridor velocity is not increased substantially.

The important implication of the decreasing marginal productivity characteristics of transport modes is that simple relationships do not exist between input and output levels. For example, increasing the supply of 1 transport mode while keeping the supply of the second transport mode constant will have an important effect on average corridor velocities at some levels, but, at other supply levels of the second mode, it will have an insignificant effect.

The family of isoquant curves shown in Figure 6 demonstrates that decreasing returns to scale are evident for the modes in this corridor. Doubling transport facilities does not double average corridor velocity. Consequently, it may be expected that optimum corridor velocity would tend toward the lower range of speeds because user benefits are more or less a direct function of average velocity. In addition, because diminishing marginal productivities exist for both modes, one would suspect that optimum velocity would tend toward the central area of the diagram.

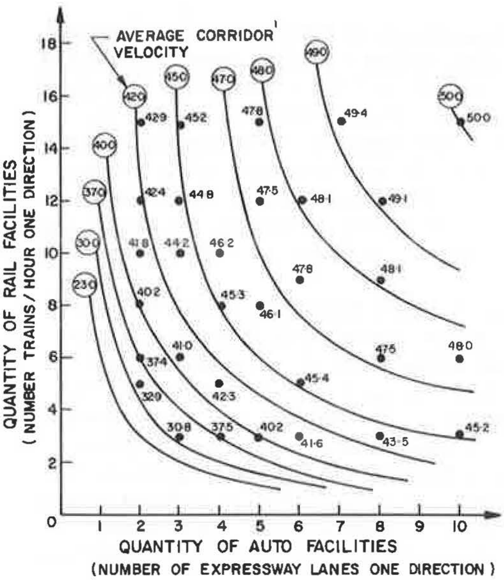
EQUILIBRIUM TRANSPORT MODE COMBINATIONS

Figure 9 shows the isocost curves of Figure 4 superimposed on the isoquants of Figure 6. For any average speed isoquant, the least cost combination of modes required to produce that speed is given by the point of tangency between the isoquant and the isocost curve immediately tangent to it. The solid dots in Figure 9 identify the least cost combinations of transport modes required to produce each of the average corridor travel speeds. These points do not necessarily represent technically feasible combinations of modes. The nearest feasible combinations of modes may be selected from the figure.

The expansion path also is shown in Figure 9. Below an average corridor speed of about 43 mph (69 km/h), the efficient transport mode combinations are located generally in the central region. That is, if transport investment is increased in the corridor, then it should be distributed in the same proportion between the modes. The expansion path indicates that, beyond about 43 mph (69 km/h), additional investment should be channeled into commuter-rail facilities. Beyond about 47 mph (76 km/h), the investment should be directed toward expressway facilities. Inspection of Figure 3 shows that expressway costs accelerate to supply 6 instead of 5 expressway lanes. However, as soon as the sixth lane has been added, increasing the number of expressway lanes becomes superior for a number of investment increments.

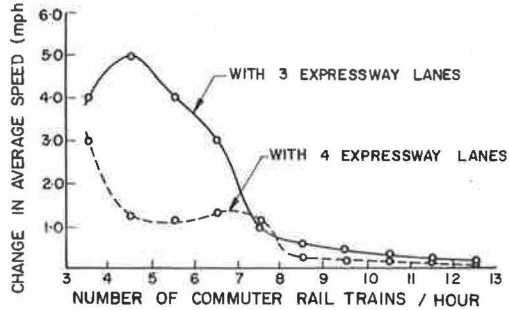
The expansion path is also a reflection of the choice- and captive-rider proportions in the corridor. Initial investments in the expressway increase the average speed of choice riders. However, after a certain level, investments in the commuter-rail ser-

Figure 6. Isoquant curves for a rail-automobile corridor.



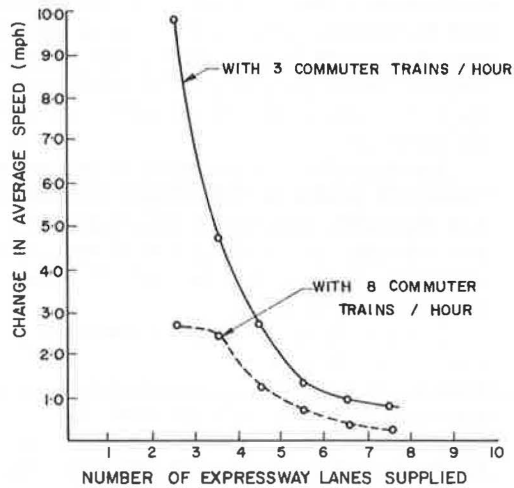
Note: 1mph = 1.6 km/h.

Figure 7. Marginal productivities of commuter-rail mode.



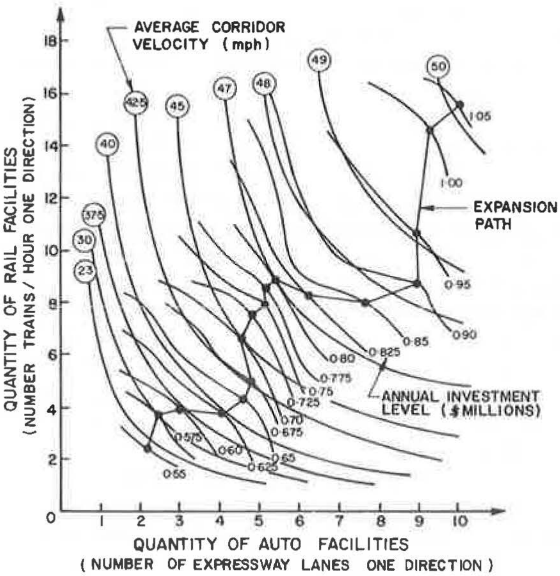
Note: 1 mph = 1.6 km/h.

Figure 8. Marginal productivities of automobile mode.



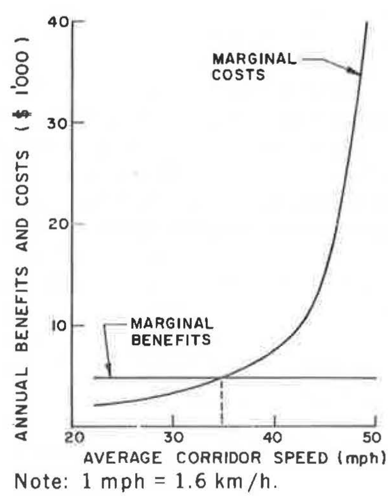
Note: 1 mph = 1.6 km/h.

Figure 9. Production diagram for a rail-automobile corridor.



Note: 1 mph = 1.6 km/h.

Figure 10. Marginal benefit and long-run marginal cost curve.



Note: 1 mph = 1.6 km/h.

vice are required before average corridor velocity will begin to increase again.

A principal advantage of displaying corridor travel characteristics in the manner used in Figure 9 is that the implications of various transport policy assumptions may be displayed easily. For example, it may be judged that the average deleterious effects of expressways are equivalent to an annual cost (for example, property value deterioration) of about \$5,000/lane/mile (\$3,100/lane/km). This unit cost may be added to the unit expressway costs. This would have the effect of rotating the isocost line so that it would have a larger negative slope. The points of equilibria then would involve use of more commuter-rail services and fewer expressway facilities.

Additional policy proposals that may be displayed readily on a diagram such as that shown in Figure 9 are the effects of downtown parking charge changes and dial-a-bus services as a feeder mode to commuter-rail stations. Both of these would influence the generalized travel costs and, therefore, the modal choice behavior of trip makers.

USER BENEFITS

Marginal user benefits between successive efficient combinations of facilities are changes in consumer surplus. In this case, because of the inelastic nature of the demand, the change in consumer surplus is equal to the change in generalized travel costs for all users. Figure 10 shows the marginal benefits and marginal costs per mile (kilometer) for the range of modal combinations identified in Figure 9.

Figure 10 shows that marginal benefits decrease rapidly at corridor velocities greater than 35 mph (56 km/h) and become fairly constant at about 44 mph (71 km/h). The optimum overall corridor velocity suggested by Figure 10 is about 35 mph (56 km/h). The nearest feasible combination of facilities produces an average corridor velocity of 36 mph (58 km/h).

At optimum velocity the annual investment cost is \$600,000/mile (\$370,000/km). Fifty-seven percent of the cost is to provide 3 expressway lanes in 1 direction, and 43 percent is to provide four 10-coach trains in the peak hour in the peak direction. The user cost is \$371,000/mile/year (\$230,000/km/year) for this condition.

ADVANTAGES OF EVALUATION METHOD

The approach to transport corridor mode evaluation described in this paper allows the economic properties of a range of alternatives to be displayed and examined in contrast to the usual project economic evaluation method. The project methodology allows the analyst to choose the best alternative from a set of mutually exclusive project alternatives. There is no guarantee, however, that the set of mutually exclusive alternatives examined includes the optimal alternative. The use of the theoretical concepts of production theory allows the analyst to display the performance and economic characteristics of the transport options in a given corridor in a quasi-continuous way. In this way the analyst may identify those regions of the production isoquant that isolate the optimal combinations of modes.

Another advantage of the approach described in this paper is that a large number of potential transport policy options for a corridor may be displayed easily and effectively. The shapes of the production isoquants are a function of the properties of the modes and the modal-split behavior of trip makers. Changes in parking charges or other non-line-haul components of the generalized cost of travel that influence modal choice may be analyzed, and changes in the production isoquants may be established. The new equilibrium positions for each alternative policy set then may be estimated.

CONCLUSIONS

This paper has demonstrated that certain concepts of production theory may be used to characterize the service properties of a bimodal corridor transport system. Transport production isoquants have been developed in terms of average door-to-door travel velocity and the amounts of input of commuter-rail and expressway facilities. Commuter-rail inputs have been expressed in terms of the number of 10-car trains/hr, and the expressway inputs have been expressed in terms of the number of expressway lanes in 1 direction.

The equivalent annual costs of various combinations of the 2 transport modes may be displayed in terms of isocost curves that allow isolation of least cost combinations of the transport modes for various average speeds. The expansion path shows the locus of least cost facility combinations and is an important concept for long-range facility planning. If it is planned to increase average speed in the corridor over time, then the facility requirement implications of such a policy may be examined easily.

The principal advantage of the approach described in this paper is its flexibility. A range of policy variables may be analyzed, and their effects may be displayed easily and effectively. In addition, nonuser effects on the equilibrium combinations of transport modes may be examined readily.

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REFERENCES

1. G. Haikalis and E. W. Campbell. Evaluating Urban Transportation Systems. Journal of City Planning Division, American Society of Civil Engineers, 1963.
2. P. T. McIntosh and D. A. Quarmby. Generalized Costs and the Estimation of Movement Costs and Benefits in Transport Planning. Highway Research Record 383, 1972, pp. 11-26.
3. D. G. Haney. Problems, Misconceptions, and Errors in Benefit-Cost Analyses of Transit Systems. Highway Research Record 314, 1970, pp. 98-113.
4. W. M. Rahman and K. B. Davidson. A Model for the Analysis and Evaluation of Urban Transport. Proceedings, Australia Road Research Board, 1968.
5. J. Freeman. A Regional Transportation Corridor Economic Evaluation Model. Department of Civil Engineering, University of Waterloo, June 1974.