ECONOMIC RELATIONSHIPS AMONG URBAN TRANSIT MODES

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Economic relationships among demand-actuated, scheduled-route, and rapid transit services are examined to determine where the operating economy justifies intensive capital investment in permanent facilities. Analysis of national experience in the more heavily populated urban areas discloses that per capita ridership is much greater in areas served by rapid transit than in areas served only by street transit service, which in turn generates far higher levels of per capita ridership than demand-actuated service. The relationships cover common situations. Unique situations (e.g., New York's unusual costs and densities and San Francisco's experimental technology) are not included. Public acceptance is measured by comparing paid ridership with population and by reference to census data on the percentage of work trips made by transit. A general similarity between the two sources is evident, but rapid transit ridership outside New York is understated because of policies involving free transfers from buses and streetcars to rail transit. This does not impair city totals, however, in which transfers are not counted as additional trips. Costs are measured by financial records based on the number of vehicles operated. The usual denominator of vehicle miles (kilometers) varies based on speed or slowness, and hourly values vastly understate the cost of service provided only during peak hours when employees must be guaranteed pay for 40 hours/week. The results are empirical but appear to be realistic.

•IN most metropolitan areas of the world, those concerned with urban planning and transportation have come to the conclusion that more people must be carried on public transport to relieve highway congestion, to lessen air pollution, to conserve energy, to augment mobility of nonmotorists, and to lessen the total cost of urban transportation. Environmental laws and regulations in the United States indicate this concern. The energy crisis of the first 3 months of 1974 gave considerable additional impetus to this issue.

IMPROVED PUBLIC TRANSPORT

A simplified but accurate method for making relative economic comparisons between the three general types of transit service to provide a meaningful tool for policy and decision making is presented. Greatly improved public transport is essential to induce voluntary use of the service and to ensure economical and convenient radial rush hour movement at reasonable speed. Circumferential movement is more difficult to attract to public transportation, and, therefore, is less likely to justify rapid transit. Toronto's Bloor Street subway is a clever compromise solution for the radial versus circumferential problem. In many cities of North America, planners, engineers, and nontechnically oriented citizens have recommended the construction of new and extended rapid transit lines to cope with the projections of metropolitan growth and saturated highway traffic volumes [Table 1 (1, 2)]. [Transit ridership does not entirely depend on characteristics of the community but more on the characteristics of the service. When rapid transit was extended through Camden County, New Jersey, in 1969, total transit use in the immediate corridor increased 115 percent. When Bay Area Rapid Transit service was inaugurated in Alameda and Contra Costa Counties in 1972, the added ridership did not cause any net diminution in bus service in these areas but

Table 1. Metropolitan areas operating or planning rapid transit.

Area	Population	Work Trips by Transit (percent)	Daily Transit Rides	Population Using Transit (percent)
Atlanta	1,390,000	10.3	193,600	13.9
Baltimore[a]	2,071,000	16.6	390,400	18.8
Boston[b]	2,754,000	19.8	580,000	21.1
Buffalo	1,349,000	12.1	120,000	9.0
Calgary	403,320	–	110,400	27.5
Chicago[b]	6,979,000	24.1	1,300,000	18.6
Cleveland[b]	2,064,000	13.8	290,000	14.5
Dallas	1,556,000	7.0	91,700	5.9
Detroit	4,200,000	8.4	330,000	7.8
Denver	1,260,000	4.7	70,000	5.5
Edmonton	495,700	–		
Los Angeles	7,037,000	4.7	665,000	9.4
Miami	1,268,000	9.0	168,000	13.2
Minneapolis-St. Paul	1,814,000	9.3	196,500	10.9
Montreal	2,743,208	–	920,000	33.6
Newark	1,856,000	–	278,000	15.0
New York[b]	11,529,000	38.3	5,000,000	43.4
Philadelphia[b]	4,821,000	24.2	1,000,000	20.7
Pittsburgh[b]	2,401,000	17.5	330,000	13.7
St. Louis	2,363,000	9.0	140,000	6.0
San Francisco	3,110,000	15.7	700,000	22.6
Toronto	2,628,000	–	1,100,000	41.4
Vancouver	1,082,350	–	260,000	24.0
Washington, D.C.[a]	2,861,000	17.3	600,000	21.0
Median without rapid transit		9.2		10.9
Median with rapid transit		22.0		21.0

[a] Electric railway under construction. [b] Includes service by electric railway.

Table 2. Operating cost experience for bus, commuter rail, and rapid transit service for 1973.

Item	Cleveland	Chicago	Philadelphia	Toronto	Pittsburgh	Typical[a]
Bus service						
Maintenance of equipment	4,000,000		12,375,000	6,600,000		6,500
Fuel	700,000		1,500,000	1,050,000		900
Conducting transportation	15,860,000		35,225,000	34,852,000		25,196
Injuries and damages	800,000		4,000,000	1,660,000		2,192
General and administrative	4,272,000		11,220,000	9,276,000		7,308
Taxes	1,068,000		3,000,000	2,222,000		1,754
Annual total	26,700,000		67,320,000	55,660,000		45,135
Number of vehicles	840[b]		1,650[b]	1,097[b]		1[b]
Per vehicle per year	32,000		40,800	50,600		45,135
Seats per bus, standard						53[b]
Per seat per year						852
Commuter rail service						
Maintenance of way and streets		1,800,000	2,900,000		15,000	6,000
Maintenance of equipment		6,000,000	11,600,000		128,000	24,000
Fuel or power		400,000	3,500,000		10,000	7,500
Conducting transportation		10,800,000	16,600,000		220,000	35,600
Injuries and damages		900,000	1,300,000		14,000	2,600
General and administrative		1,200,000	3,600,000		78,000	5,200
Taxes		1,700,000	3,300,000		4,000	6,600
Annual total		22,800,000	42,800,000		470,000	87,500
Number of vehicles		296[b]	446[b]		4[b]	1[b]
Per vehicle per year		77,000	96,000		117,500	87,500
Seats per car						120[b]
Per seat per year						729
Rapid transit service						
Maintenance of way and streets	500,000		2,200,000	3,200,000		6,000
Maintenance of equipment	900,000		3,000,000	3,600,000		7,330
Power	600,000		2,400,000	2,400,000		4,850
Conducting transportation	1,700,000		8,500,000	3,900,000		15,720
Injuries and damages	100,000		700,000	400,000		1,350
General and administrative	1,100,000		4,200,000	800,000		7,500
Taxes	400,000		1,100,000	700,000		2,250
Annual total	5,300,000		22,100,000	15,000,000		45,000
Number of vehicles	118[b]		490[b]	410[b]		1[b]
Per vehicle per year	45,000		45,000	36,600		45,000
Seats per car						83[b]
Per seat per year						542

[a] Per transit vehicle. [b] All values are in dollars except number of vehicles and seats per vehicle.

resulted in a significant overall increase. When rapid transit service was temporarily suspended in Newark in 1971, ridership on the route declined 75 percent.]

RAPID TRANSIT

Rapid transit is generally intended to refer to a collective method of moving groups of people in multiple vehicles capable of being operated by one person on an exclusive, grade-separated right-of-way not shared with other vehicles. The creation of such a right-of-way can be very expensive if none is readily available, and indeed some of the current projects exceed a billion dollars in some cities. However, where rights-of-way can be obtained readily or where travel volume is great, rapid transit is the most attractive, efficient, and least costly method of moving people in quantity. Little objective qualitative operational economic justification has been developed beyond the general idea that the cost of not providing it is greater than the cost of providing it.

DEMAND-ACTUATED TRANSPORT

At the opposite end of the spectrum, where there is little or no observable transit volume and no radial movement, demand-actuated urban transit is obviously the logical choice for economically maximizing service.

Thus, there are three general types of transit service: (a) demand-actuated, (b) conventional scheduled route (bus or trolley) on shared public rights-of-way, and (c) private right-of-way rapid transit (or commuter rail). Each has its own unique characteristics, but all three are capable of taking a nonmotorist from one point to another at a reasonable cost. Exclusive busways are a hybrid of conventional and private right-of-way transit and combine shared and exclusive rights-of-way. Their costs can be calculated the same way.

Notation and values of 1974 transit cost factors used are as follows (1 mile = 1.6 km):

A_b = annual operating cost per bus = \$45,135;
A_c = annual operating cost per commuter rail car = \$96,000;
A_r = annual operating cost per rapid transit car = \$46,100;
A_t = annual operating cost per demand-actuated bus = \$55,000;
C_b = capital cost per bus = \$48,000;
C_c = capital cost per commuter rail car (diesel + $^{1}/_{6}$ locomotive) = \$320,000;
C_r = capital cost per rapid transit car = \$320,000;
G_b = capital cost of garage per bus = \$20,000;
G_c = capital cost of shop per commuter rail car = \$30,000;
G_r = capital cost of shop per rapid transit car = \$25,000;
M = round trip mileage of route;
P = capital cost of rapid transit, at-grade alignment per mile = \$4,000,000, aerial alignment per mile = \$12,000,000, depressed alignment per mile = \$20,000,000, and underground alignment per mile = \$40,000,000;
R_b = capital recovery factor for bus = 0.100;
R_c = capital recovery factor for commuter rail car = 0.075;
R_g = capital recovery factor for garage or shop = 0.070;
R_p = capital recovery factor for right-of-way = 0.062;
R_r = capital recovery factor for rapid transit cars = 0.075; and
X = one-way peak-hour passenger volume for equal cost.

The various speed variables are as follows:

S_b = scheduled speed of bus (typical) = 10 mph,
S_c = scheduled speed of commuter rail = 30 mph, and
S_r = scheduled speed of rapid transit = 25 mph.

The speeds used are

1. Central business district peak bus speeds = 3 to 4 mph,
2. Suburban arterial bus speeds = 14 mph,
3. Commuter rail speed = 1 min/mile plus 1 min/stop, and
4. Rapid transit speed = 0.9 min/mile plus 0.9 min/stop.

(Variables pertaining to commuter rail are included although they are not specifically used in this paper.)

A comparison of exclusive busway and rail rapid transit involving 4 miles (6.4 km) of exclusive busway, 1 mile (1.6 km) of CBD streets, and 3 miles (4.8 km) of suburban streets is given below:

$$(A_b + C_b R_b + G_b R_g)MX/64S_b + PR_p M/2 = (A_r C_r R_r + G_r R_g)MX/150S_b + PR_p M/2 \qquad (1)$$

where

1 mile (1.6 km) of busway costs \$10,000,000,
1 mile (1.6 km) of rail subway costs \$40,000,000,
4 miles (6.4 km) of rail aerial system cost \$12,000,000, and
2 miles (3.2 km) of busway cost \$4,000,000.

Therefore,

$$\begin{aligned}&(\$45{,}135 + 48{,}000 \cdot 0.1 + 20{,}000 \cdot 0.07)16X/64 \cdot 16 + \$40{,}000{,}000 \cdot 0.062\\ &= (\$46{,}100 + 320{,}000 \cdot 0.075 + 25{,}000 \cdot 0.07)14X/150 \cdot 25\\ &\quad + \$56{,}000{,}000 \cdot 0.062 \qquad (2)\end{aligned}$$

and

$$X = 1{,}851 \text{ one-way passengers/peak hour to justify rail service at time value} = 0 \qquad (3)$$

Following is a time value iteration for a 6-mile (9.7-km) average trip at 25 mph (40 km/h) for rail = 14.5 min and at 18 mph (29 km/h) for bus = 20 min:

$$\$536X = \$992{,}000 - 5X \cdot \$0.165 = 287 \text{ days} - 237X \qquad (4)$$

and

$$X = 1{,}283 \text{ one-way passengers/peak hour to justify rail service at time value of } \$0.03/\text{min} \qquad (5)$$

Equations 1 through 5 do not justify either an exclusive busway or rail rapid transit;

each mode must be compared with surface transit to determine basic justification.

Light rail service can be similarly treated. Taxi service could be called demand-actuated service but is not usually considered transit service because of its cost and its sporadic nature.

JUSTIFICATION OF TRANSIT MODE

Civic authorities often ask, At what volume of patronage is rapid transit justified and when is demand-actuated service the proper choice? There are no simple answers to these questions, but neither is the choice purely optional. Rapid transit operating costs per passenger-mile (kilometer) are normally the lowest, and the service attracts the highest ridership; however, investment is great, and this raises the question of economic justification. There is only a 25 to 33 percent operating cost difference between demand-actuated and scheduled route service (3), but the use factor causes great variation in unit passenger costs. The question of relative justification can be answered only if it is known how expensive a specific project will be and how heavily it will be used.

All forms of vehicular movement require expensive rights-of-way, but common practice has been to provide city streets without regard to economic analysis because they are considered necessary. Public transport using these streets is assumed to have no fixed cost, and the local fuel tax, if any, is the only charge for right-of-way. This cost varies on many public transport systems from 0 to $0.02 vehicle mile ($0.013/km) or 1.5 percent of operating costs. This charge is unrelated to the acquisition of the street or highway right-of-way, property taxes on its value, interest on its investment, snow removal, and police and traffic control cost, all of which are included in the traditional method of calculating rapid transit or commuter rail costs.

As a practical matter, street transit vehicles operating in the general traffic stream can share the public road for $0.02/mile ($0.012/km) or for free, provided the traffic volume does not become so large that an additional lane of traffic is required [the value of $0.02/mile ($0.012/km) is obtained by dividing the tax/gal (tax/liter) by the miles/gal (km/liter)]. For an exclusive lane, land must be acquired at great capital cost. There is seldom a necessity to measure the cost of single-unit street vehicles on an exclusive right-of-way. Their higher operating cost per passenger renders them incapable of amortizing the cost of their right-of-way at less than multiple-unit rapid transit service cost (Table 2). This is because the cost of acquisition and construction of a heavy-duty private right-of-way, whether at grade, subway, or aerial, is not much less costly per unit of bus capacity than the construction of a rapid transit line. The civil engineering costs are similar, but buses need no power supply and have no safety signal system and, therefore, save up to $2 million/mile ($1.2 million/km).

The actual fully allocated cost of rapid transit, although it is often lower per ride than for surface transit in a specific corridor, will vary widely depending on whether the specific type of right-of-way construction is on an existing right-of-way, at grade, or above or below grade and also depending on station spacing.

ECONOMIC JUSTIFICATION FOR RAPID TRANSIT SERVICE

Although rapid transit may be a necessity for many cities, including some that do not have it, far too little attention has been paid to its economic justification on an operational basis. Capital and subsidies are not unlimited even if traffic congestion is. Too many plans assume an unlimited need for subsidy and, in so doing, place rapid transit planning at the personal whims of the designer instead of under the self-policing, automatic, and accurately guiding steady hand of the marketplace (4).

This is not to suggest that private enterprise should undertake rapid transit development because that has become impossible under existing tax systems and public policies. It should be enough for the public to lend its full faith and credit, supplemented by public grants when the giving of the grant reduces the cost of living for the general taxpayer.

There is nothing wrong with tax support for a desirable and necessary public facility, but a nonelastic yardstick is necessary to measure the effectiveness of the planning and design work. Rapid transit must be built where it will do the most good, obviously, but this can be determined only after all the directly relevant factors have been converted into real dollars for realistic comparison. Although worthy of full consideration, indirect benefits other than travel time are not likely to weigh significantly in the proper choice; therefore, they are not included, not only for simplicity but also because few could agree on them. Time differentials can be equated to modal choice, resulting in a demonstrated value for time. This modal choice is the reciprocal of added revenue from the additional patronage generated by speed.

The economic relationships between rapid transit and surface street transit and between scheduled and demand-actuated service are expressed in equation 6. Equation 6 is simplified, for this purpose, on the sound assumption that rapid transit should always serve a relatively high traffic volume or it should not be built.

$$\overset{\text{(bus model)}}{(A_b + C_bR_b + G_bR_g)MX/64S_b} = \overset{\text{(rapid transit model)}}{(A_r + C_rR_r + G_rR_g)MX/150S_r} + PR_pM/2 - \$1,282.5(1/S_b - 1/S_r) \tag{6}$$

[The fixed right-of-way cost per passenger, based on current high traffic volumes, will not vary greatly per incremental unit because of the high use. If there are only a few short trains per day, it would be necessary to treat right-of-way maintenance as a fixed cost, but rapid transit is never built for such low volume. This is more of a real problem with railroad operation for which low-volume operation is sometimes prudent.]

TRANSIT OPERATING COSTS

Review of transit operating costs in all urban metropolitan areas reveals that, with few exceptions, costs are reasonably consistent if equated to the vehicle rather than to the mile (kilometer) or hour as is usually done [Table 3 (1)]. Rapid transit construction costs are also reasonably consistent for similar types of construction. With this type of information, planners and transit authorities can set up the mathematics of the circumstances, work through the proposed formula, and thus obtain a preliminary but realistic determination of the merit of rapid transit for specific application (Figure 1).

For demand-actuated service at the other end of the spectrum, a use formula will be devised to assist in realistically determining where scheduled service should stop and where demand-actuated service should take over. Contrary to popular expectations, demand-actuated service seldom attracts more rides per capita than good scheduled service; therefore, quality of service is not a financial trade-off problem [Table 4 (5)]. Of course, where demand-actuated service enters new territory, it will increase the transit rides per capita, but, where there is a choice, the longer, uncertain waiting time and higher cost seem to more than offset the added convenience. For convenience alone, the taxi has already performed the necessary service.

Admittedly, economic considerations are not the sole criterion. It is usual for rapid transit to increase the number of transit riders per capita greatly so that traffic relief, property values, safety, and economic stimulation may have as much to do with rapid transit justification as the operational economy has to do with it. But one must be careful to avoid delusions in these unquantified areas of interest [Figure 2, Tables 1 and 5 (2, 6, 7, 8, 9)].

COST MODEL FOR TRANSIT TRAVEL

The many relevant facts for direct operating determinations as given above in the notation and explanation of the variables are readily available for use in substitution in an empirical but relatively accurate model.

Table 3. Urban transit operating costs for 1973-1974.

		Annual Cost (dollars)	
Area and Mode	Vehicles	Total	Per Vehicle
Baltimore	1,000	45,000,000	45,000
Chicago bus	2,762	168,000,000	61,000
Chicago rapid transit	1,181	59,000,000	50,000
Chicago C&NW railroad	296	22,800,000	77,000
Cleveland bus	840	26,700,000	32,000
Cleveland rail	172	7,560,000	44,000
Detroit	1,114	47,000,000	42,300
Los Angeles	1,525	60,000,000	39,300
Philadelphia bus	1,650	67,320,000	40,800
Philadelphia rapid transit	490	22,100,000	45,000
Philadelphia railroad	446	42,816,000	96,000
Pittsburgh bus	915	43,371,000	47,400
Pittsburgh rail	95	5,629,000	59,250
St. Louis	824	23,500,000	28,500
San Francisco bus	1,300	55,705,000	42,850
Toronto bus	1,097	55,660,000	50,600
Toronto rapid transit	410	15,000,000	36,600
Washington, D.C.	1,353	60,000,000	44,500
Total bus	14,473	653,000,000	45,135
Total rapid transit	2,348	108,400,000	46,100

Note: New York, Boston, and Montreal were excluded to avoid unusual circumstances. Other omissions were caused by inadequate data.

Cost of transit operation has usually been simplistically calculated in terms of vehicle miles (kilometers) or somewhat more accurately in terms of the vehicle hour. The cost per vehicle is more consistent and equates to $1.46/bus-mile or $14.60/hour. The most accurate equivalent would be $11,000/bus plus $7.33/hour plus $0.36/bus-mile for 1974.

Figure 1. Investment versus traffic volume.

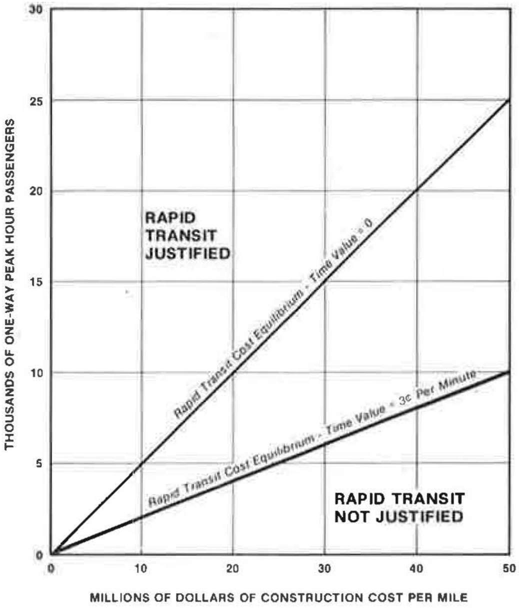


Table 4. Demand-responsive transportation systems.

										Control	
Item	Regina	Buffalo	Bay Ridges	Haddonfield	Batavia	Ann Arbor	Columbus	Columbia	Davenport	PAT[a]	Harrisburg
Population served	15,200	7,000	14,000	25,000	18,000	13,000	37,000	17,300	125,000	100,000	170,000
Average daily fares	1,200	360	530	750	350	214	400	54	1,440	25,000	12,000
Annual ridership	305,000	120,000	193,450	225,000	105,000	64,200	127,700	13,500	480,000	6,750,000	3,600,000
Riding habit, annual per capita	20.0	17.0[b]	13.8	9.0	5.8	5.0	3.4	0.8	3.8	67.5	21.0
Buses including spares	6	7	5	12	5	4	5		40	95	60
Annual operating cost, dollars	217,770	245,000	83,000	500,000[c]	157,500	83,333	214,048		566,400	4,200,000	1,500,000
Annual revenue, dollars	61,000		41,000	120,000	53,000	29,000	25,540			2,950,000	1,440,000
Fare, dollars	0.35		0.25	0.50	0.40	0.50	0.20	0.50	—[d]	0.40	0.35
Cost per ride, dollars	0.71	2.02	0.43	2.20	1.50	1.35	1.68	2.50	1.18	0.62	0.42
Cost ratio over fare	2.0		1.7	4.4	3.7	2.7	8.4	5.0		1.5	1.2
Cost per passenger-mile, dollars	0.35		0.22	0.70	0.75	0.66	0.75			0.12	0.17
Annual cost per bus, dollars	36,295		16,600	40,500	31,500	20,875	42,810		14,160	45,000	25,000
1972 wage rate, dollars	4.38		3.64	4.75	3.00	4.00	—[e]			4.75	4.00
Passengers per mile	1.76		1.5	0.3	0.43	0.7	0.8			4.0	2.0
Passengers per hour	18.8[f]		16.5[f]	4.1	9.0	7.85	7.6	4.4		48.0	20.0
Many to one, percent	55		76	25		93	5			85	80
Miles per hour	10.6		11.0	13.7	20.0	11.2	9.5			12.0	10.0
Rank in trip generation	3	4	5	6	7	8	9	11	10	1	2
Rank in economy	4	9	3	10	7	5	8	11	5	1	2

Note: 1 mile = 1.6 km.

[a] Port Authority Transit routes 35, 36, 37, and 38/42 in suburban Pittsburgh.

[b] Only population over 59 years eligible in model cities only.

[c] Excludes start-up costs and demonstration overhead.

[d] Taxi.

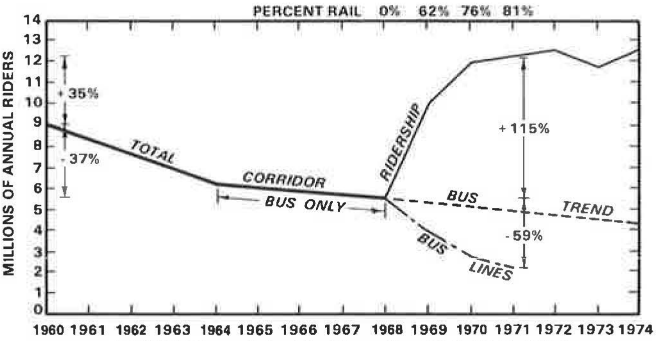
[e] High.

[f] Semifixed, scheduled peak-hour service feeding trunk transit lines.

Table 5. Rapid transit impact on ridership.

	Surface Transit Rides		Rapid Transit Rides		
Area	Amount	Per Capita	Amount	Per Capita	Total Rides per Capita
Baltimore	117,136,000	56.5			56.5
Buffalo	36,983,730	28			28
Dallas	27,520,000	17.5			17.5
Detroit	94,343,800	22.5			22.5
Los Angeles	199,500,000	28			28
Minneapolis-St. Paul	59,000,000	32			32
St. Louis	52,180,000	22			22
Washington, D.C.	150,000,000	52.5			52.5
Median without rapid transit	76,500,000	34.5			34.5
Boston	81,000,000	29.5	73,000,000	26.5	56
Chicago	293,586,000	42	147,806,000	21	63
Cleveland	71,000,000	34.5	16,000,000	8	42.5
New York	821,220,000	71	1,122,456,000	97	168
Philadelphia	139,000,000	29	142,006,000	30	59
Pittsburgh	80,000,000	33	6,000,000	2.5	35.5
Toronto	238,000,000	90.5	118,000,000	45	135.5
Median with rapid transit	95,013,000	34.5	72,981,000	26.5	61

Figure 2. Ridership increase in southern New Jersey rapid transit system.



SOURCE: Wharton School, U. of Penna. Nov., 1972. DRPA - PAT Co.

Street transit costs depend on the annual cost of operation per unit A_b plus the annual increment of investment in rolling stock C_b, which is determined by multiplying the total by the capital recovery factor R (to reflect depreciation and interest costs), plus similar investment costs for fixed facilities such as garages (G_bR_g). The sum of these ($A_b + C_bR_b + G_bR_g$) constitutes the total annual cost per unit of rolling stock.

Surface Transit

The number of vehicle units can be determined by dividing the number of riders one way in the peak hour at the maximum load point by the scheduled capacity of each vehicle (64) [i.e., 40 × 8 = 320 $ft^2/5\ ft^2$ (29.73 $m^2/0.46\ m^2$)]. This will give the number of units required for a service for 1 hour. The actual number of vehicles, plus 10 percent for spares, will vary from this as the scheduled round trip and recovery time varies from 1 hour.

The annual cost of surface transit operation can be expressed by dividing the number of round trip miles M by the scheduled speed S_b in mph (km/h) and multiplying the result (M/S_b) by the predetermined number of vehicles (passengers/64). Thus, the annual cost of surface transit operation for a given route will be

$$(A_b + C_bR_b + G_bR_g)(MX/64S_b)1.1 \tag{7}$$

For demand-actuated service, the formula is similar except that the number of vehicles is determined by the ratio of one vehicle for each eight passengers per hour. This is the practical limit of achievement to date for unscheduled service without excessive waiting time.

Rapid Transit

Rapid transit operating costs can be determined the same way, except that the private right-of-way adds capital cost and permits the passenger loading to be increased from 64 per unit to 150 [i.e., 75 × 10 ft = 750 $ft^2/5ft^2$ (≈ 69.97 $m^2/0.46\ m^2$)] with larger vehicles if 5 ft^2(0.46 m^2) of vehicle size [4.5 ft^2(0.42 m^2) of interior space] are allocated to each passenger. This is the practical limit of loading if each passenger is to have unfettered access to a door at his or her stop and a handhold or a seat while riding. The cost of the exclusive right-of-way will be called P, multiplied by the capital recovery factor R_p times the length of the route M/2. The total cost per year then becomes

$$(A_r + C_rR_r + G_rR_\phi)\ MX/150S_r + PR_pM/2 \tag{8}$$

By equating this rapid transit cost with the surface transit cost, X becomes the number of passengers one way per peak hour that determines the break-even point of rapid transit economy as compared with surface transit service.

The formula becomes practically meaningless at volumes above 6,000 passengers/peak hour/artery because surface transit above this figure requires either trolley trains or an exclusive pair of street lanes for bus loading and passing. The delays of high-volume street transit at loading zones usually limit CBD speeds to 3 or 4 mph (4.8 or 6.4 km/h). This idea is difficult to sell to passengers, and the delays make operation very expensive. When the full cost of providing two more lanes of city street is considered, rapid transit will likely be more economical and more expeditious and attractive for high-volume travel.

Demand-Actuated Model

The economic justification for demand-actuated service arises from the ability of one vehicle unit to cover more territory, even though it serves few passengers. It is the low-load factor of scheduled service that justifies substitution of demand-actuated service rather than line loading at capacity. The added dispatching and control costs for demand-actuated service add 25 to 33 percent to operating cost (3), and the eight passengers per hour limit the efficiency of the service. The equation for substitution of demand-actuated service for scheduled service is, thus, quite simple. A demand-actuated bus will serve eight peak-hour riders per hour at a cost of 1.25 times the cost of scheduled service. Thus, when a scheduled-service bus is serving less than six and one-half peak-hour passengers per hour or when two buses are serving less than eight passengers per hour, demand-actuated service is prudent. Urban area scheduled transit service in 1974 is costing an average of \$14/hour (Note, Table 3) at nominal \$5.50/hour wage scales. Therefore, the most realistic cost estimate for demand-actuated service will be about \$17.50/hour or \$2.20/passenger minimum when the service is fully demand-actuated and unscheduled and based on current metropolitan wage rates. Table 4 gives some demand-actuated services at less than current wage scales.

COMPARISON OF URBAN TRANSIT EXPENSES

Table 2 gives operating expenses that are typical except for New York City and Boston where unusual restraints apply for all urban transit modes.

These costs have been developed from the average of the fast, low-volume, newer system in Cleveland, the older, higher volume, more extensive system in Philadelphia and the newest, high-volume system in Toronto. All three systems have similar modern surface vehicles, although in Cleveland conventional rapid transit is supplemented by surface rail vehicles used for light-volume rapid transit service (Table 3).

The interest used to compute the costs is based on the local government rate of 5½ percent. Federal funds, particularly highway funds, are in part on a cash-flow basis devoid of interest, but the federal debt precludes debt-free capital without interest. It is assumed that private capital will no longer be used to build highways or rapid transit lines.

Substituting the standard proved values in the equation yields

$$(A_b + C_bR_b + G_bR_g)MX/64S_b = (A_r + C_rR_r + C_rR_g)MX150S_r + PR_pM/2 \qquad (9)$$

Based on equation 9, X = 2,100 passengers on an abandoned converted railroad right-of-way, 2,100 in an expressway median, 6,300 on an aerial line, 10,500 in a depressed open alignment, and 21,000 in a full subway. In most cases, a single rapid transit line will include several of these different elements, and the calculations will be modified to reflect the variation. For commuter rail service, the break-even point comes at 943 passengers/peak hour for diesel service requiring \$1 million/mile (\$0.6 million/km) for track upgrading and stations.

For example, given 18 miles (29 km) of railroad on which commuter passenger service is being considered, the break-even point for commuter rail can be determined as follows:

$$(A_b + C_bR_b + G_bR_g)MX/64S_b = (A_r + C_rR_r + G_rR_g)MX/150S_b + PR_pM/2 \qquad (10)$$

where the suburban bus schedule speed into city with recovery time = 14 mph (23 km/h); all passengers are seated at peak, 64 is reduced to 53 and 150 is reduced to 104; and commuter rail right-of-way embellishment costs \$1 million/mile (\$0.6 million/km). Therefore,

$$(\$45{,}135 + 48{,}000 \cdot 0.1 + 20{,}000 \cdot 0.07)\ 36\ X/53 \cdot 14 = (\$87{,}500 + 320{,}000 \cdot 0.075 + 30{,}000 \cdot 0.07)\ 36X/104 \cdot 30 + (1{,}000{,}000 \cdot 0.062)36/2 \tag{11}$$

and

$$X = 943 \text{ one-way passengers in peak hour justify rail service at time value} = 0 \tag{12}$$

Following is a time value iteration for 943 one-way passengers in peak hour that typify 3,772 average daily two-way passengers, each saving an average of 23 min worth \$0.69 at \$0.3/min as derived. The annual time saving has a value of \$2,603/day or \$728,000/year to be applied against construction cost. Thus,

$$\$2{,}490\ X = \$1{,}306\ x + 1{,}116{,}000 - 4X \cdot \$0.69 \cdot 281 \tag{13}$$

and

$$X = 570 \text{ one-way passengers in peak hour justify rail service time value} = \$0.03/\text{min} \tag{14}$$

Many planning studies also include the value of time saved, which will reduce the break-even volumes of travel to much lower levels. It will also reflect the superior elasticity of a more competitive service in making comparison with other alternatives. Mathematical analysis of traveler choice indicates that modal split and traffic assignment techniques are most accurate when a derived value is put on travel time [\$0.0167/min in 1960 (10)]. When this value is updated to 1974, approximately \$0.03/min will most realistically reflect travel patterns. Since surface transit averages 6 min/mile (3.7 min/km) in urban centers and rapid transit averages about 2.5 min/mile (1.6 min/km), the saving of 3.5 min is worth \$0.105 in offsetting capital cost of construction. Accordingly, the expression $-85{,}500\ (1/S_b\ 1/S_r)(\$0.03XM/2)$ should be appended to PRM/2 in equation 9. This will reduce the subway break-even cost from 21,000 one-way passengers/peak hour to 5,825 at \$0.03/min saved. Because there are excellent time savings on at-grade rights-of-way, the cost can become zero or less. This means that the project rate of return exceeds the amount calculated. Since most of the federal highway program has been justified on time savings, balanced transportation planning requires similar assumptions for public transit.

Wherever the speed and regularity of rapid transit service will attract volumes of peak-hour travel that are greater than the values of X calculated by the model in this paper, investment and construction are likely to be justified.

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