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FOREWORD

The papers in this RECORD discuss aspects of the demand for public transportation, passenger characteristics, and system design.

In the paper by Saltzman and Solomon, the authors trace trends in the transit industry from the early 1900s to the present. The paper finds that governmental regulatory and antitrust actions have exacerbated declining ridership trends and reduced the transit industry's ability to adopt new technology. The industry's foundation in a fixed route system has also been a contributing factor in the lack of innovation in services offered.

Wohl examines costs and ridership data on the Cleveland Hopkins Airport rapid transit extension to determine its financial and economic feasibility. The paper includes an attempt to ascertain the level of consumer surpluses and the effects of different price levels. Other impacts, such as effects on traffic congestion, are considered.

Brown describes a study of the use of subjective preferences as a way of determining the possibility of shifting citizens' travel modes (i.e., from automobile to bus transit). The paper describes a propensity model developed to study the effects of automobile parking fees, total transportation times, and walking distances on modal choice. The study indicates that walking times and transit frequency must be radically different from the current standards if there is to be a substantial diversion toward transit. Transit headways must be $4\frac{1}{2}$ minutes or less, and walking distances at terminals should be no more than 2 minutes. Increases in parking charges were found to be effective in creating a shift to transit.

Schmidt, Arnold, and Levy report on research conducted on feeder transportation systems for the San Francisco Bay Area Rapid Transit system. In the suburban county studied, the majority of the residents that commuted to the city owned two or more cars. The study found that conventional bus systems would not substitute for the private automobile and that they would not be feasible as a feeder system or as a combined feeder-local transit system. New forms of public transportation will be needed. The study suggests the possibility of using small, publicly owned, electrically powered automobiles to solve the transit feeder system problem.

In the last paper, Rea describes a screening model for the design of public transportation systems which is capable of defining transit system configurations subject to given policy constraints and hardware systems. The model is based on the "service specification" concept, which integrates hardware systems and operating policy for use on transit links having a given range of low levels and a known demand.

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HISTORICAL OVERVIEW OF THE DECLINE OF THE TRANSIT INDUSTRY

Arthur Saltzman, North Carolina Agricultural and Technical State University; and
Richard J. Solomon, Solomon and Schwartz and Associates

• THE developmental history of the U. S. public transportation industry has had much to do with shaping the declining role that mass transit plays in urban transportation today. This paper deals with the trends that have structured the industry, beginning with a discussion of the forces of decline.

Many theories about the actual mechanism of this decline have been held by urban planners. Our hypothesis takes into account the possibility that inadequate understanding of the interacting mechanisms within the formerly private transit infrastructures by the various local and national governments eventually placed the operating companies on such poor financial footing as to make essential the current efforts of governments toward direct subsidy in order to rectify their previous mistakes.

We have emphasized the financial and regulatory problems that have hampered the transit industry. It is recognized, however, that transit ridership has, for the past 50 years, slowly and predictably declined after leveling off during the immediate post-World War I years—well before the automobile had its major impact on suburbanization. However, any attempts by the industry to reverse its declining fortunes during the critical years of rapid urban change were hampered by the effects of the governments' antitrust actions against elements of the transit industry. Not all of the blame for the problems facing the transit industry can be placed on state and federal governments. It is our opinion that the industry's inability to respond to changing public needs within reasonable periods of time and its lag in adopting new technology, save as stopgap measures, have exacerbated declining ridership trends and accelerated change in the mobility habits of the public.

FUNDAMENTAL PROBLEMS

The public transportation industry, mass transit in particular, has tended to be quite conservative toward innovative operating practices. Any departure from the standard or any new method of carrying passengers on a common-carrier basis is viewed only as a threat to the existing infrastructure instead of a way to offer better or more desirable service to the public and perhaps to gain a larger share of the urban transportation market.

Adaptation to external changes in standards and patterns of urban living has always been difficult, if not impossible, for mass transit operators. This was indicated quite early by the reaction of an industry spokesman to a study of psychological problems on transit riding made in 1916 by Harvard University for the industry. The study clearly showed that most patrons were dissatisfied with two basic aspects of conventional transit service: crowding and waiting (time loss). The director (1) of the American Electric Railway Association's Bureau of Fare Research summed up the prevailing attitude of the operators by stating that passengers have been shown by this study to consistently overestimate waiting time and exaggerate congestion; therefore, their "knowledge as to technical details of operation is limited and expressions of opinion . . . are varied and confused." He discounted the opinions of passengers instead of trying to respond to their needs.

Sponsored by Committee on Passenger and Freight Transportation Characteristics.

Prior to 1912, electric street and rapid transit railways were prosperous monopolies that carried almost all urban passenger trips. Per capita ridership on street railways increased faster than did urban population until the end of World War I; hence, investments in street railway companies were extremely attractive so long as operating costs remained stable. Most street railway operators had anticipated that ridership and earnings would increase indefinitely as population grew; costs were expected to decline as utilization of investments increased. Labor rates were expected to remain low and stable. Because technological obsolescence was not anticipated, competition was unthinkable because of the franchise monopolies that had been granted to the street railway operators (2; 3, p. 2235).

As we explore the structure of the urban transit industry, its evolution, and its responses to vital challenges, we should keep in mind the initial expectation of the operators, i.e., an ever-prosperous street railway industry, unchanging in an unchanging world. It played a critical role in producing the resistance to new ideas that numerous observers have pointed to as a central characteristic of the transit industry in recent decades. In assessing transit's declining impact on urban transportation, we give greater weight to management's inflexibility of response to drastic changes in demand than to the operations' decreasing net revenue. Lack of ability to accurately predict and gauge these trends and, therefore, to adequately cope with the changing market has to this day been a major industry shortcoming.

It is especially noteworthy that unresponsive route structures, stemming from the street railway days, have been ingrained in the industry. Urban transit operators have locked themselves into certain modes of operation and have had difficulty envisioning new means of public transportation service. Operators have thought of themselves as merely being in the street railway, bus, or taxi business; they have not looked upon themselves as being in the business of serving public transportation needs with all available tools in an ever-changing competitive market.

The industry has had more than its share of financial problems. At several critical times in its history, the industry did not have the resources to support innovation. A few examples are as follows:

1. Beginning in about 1916, severe inflation increased operating costs (especially wage rates), while revenues remained steady almost wholly because of inflexible fare structures.
2. By the end of World War I, one-third of the transit companies were in bankruptcy. Much of this was probably due to overcapitalization based on anticipated earnings from future growth in ridership.
3. Utilization of depreciation reserves to pay preferred indebtedness was generally practiced, producing service deterioration, at the same time that per capita transit ridership was beginning to decrease.
4. The Securities and Exchange Commission (SEC) interpreted the Public Utility Holding Company Act of 1935 as prohibiting most electric power and petroleum trusts from continuing their wide-ranging financial interests in transit operations. This severely undercut the remaining financial base of the transit industry during the Depression, denying it both capital aid and management aid at a critical point when they were needed to support innovation and modernization.
5. Moving into the vacuum left by the power trusts, General Motors Corporation (GMC) and other suppliers provided capital and management aid. Through stock ownership in operating companies, such as National City Lines (NCL), these suppliers underwrote street railway replacement beginning in about 1936 or 1937. In 1947, the Justice Department sought an injunction against NCL and its suppliers in order to stop them from engaging in a violation of the antitrust laws. (The antitrust action was ultimately resolved 19 years later when GMC signed a consent decree severely curtailing its interests in mass transit development.) Once again, at a time when the industry needed capital to replace its worn-out fleets (in this instance, after a wartime ridership surge), it was again denied by an unimaginative application of the federal statutes.

REGULATORY PROBLEMS

Local regulatory restrictions on the transit industry were further impediments to innovation. Early street railway operators went to great lengths to secure exclusive franchise rights. Given the absence of competition and rapidly increasing total ridership through most of the first quarter of this century, there seemed to be no reason for operators to further improve their technology and operations. Strict regulatory laws designed to prevent entry into the transit business were enacted, ensuring a monopolistic position for transit operators. Eventually, mergers between remaining competing operators were forced by the holding companies' financial backers.

By the end of World War I, no one having a unique concept of common-carrier transit was allowed to compete for a share of the public transportation market though the operators' share of total urban trip-making was rapidly diminishing as car ownership began to increase. Often, the restrictions enacted to bar competition also prevented established operators from trying new types of service or equipment. For instance, most operators had to have new franchise laws enacted to permit the introduction of motorbuses or even to reduce the crew on streetcars from two men to one. Furthermore, anti-jitney laws are generally written so as to prevent demand-responsive nonfixed routes, operated as common carriers, from being established even today. Fixed routes, one standard of service, and inflexible fares have always been part of the public transportation scene.

FIXED FARES, INCREASING COSTS, AND LACK OF CAPITAL

Most street railway companies pressed for a fixed flat rate (usually 5 cents) to be written into their franchises as a hedge against future political pressures to reduce fares (4, pp. 12-20; 5). The public, too, accepted this concept and later believed the 5-cent fare to be its right. From the public's viewpoint, the electric railway's 5-cent fare was often a reduction from the zone fares charged by the horsecars or the 10- and 25-cent fares charged by horsedrawn buses. Furthermore, many franchises promised free transfers and implied an intent to merge the several competing streetcar companies normally found operating in medium-to-large cities.

As early as 1911, some elements in the industry noted a decline in profits because of increased labor costs. The next year, the influence of Ford's low-cost Model T began to be felt; almost simultaneously came the rise of "jitney" common-carrier motorcar competition.

The industry association appointed a committee to investigate remedies, resulting in a study of cost of service in 1916 by F. W. Doolittle (1) and another text in 1917 on fare structures (6). Both studies recommended changes from the flat fare system but suggested little toward making this politically feasible other than recommending the "education" of the public and the regulatory commissions. Competition from the automobile was primarily perceived as a threat when run as an unregulated common-carrier jitney (1). Transit ridership was assumed to continue to rise as soon as that threat was removed by regulation.

During World War I, the industry was "... caught between the upper millstone of the customary and franchise-fixed fare of five cents and the nether millstone of rapidly rising wartime operating costs" (7, p. 86). While ridership and revenue remained relatively constant, operating costs were increased by severe inflation during the war. By 1919, one-third of the operating companies were bankrupt. So serious was the plight of the urban transit industry that in 1919 President Wilson appointed the Federal Electric Railway Commission to publicize and investigate the program (8, 9).

In the industry's brief to the 1919 Federal Commission, the technological and financial developments leading to this overcapitalization were explained as being due to an early lack of foresight about technological change. Early resistance to the introduction of electricity, when it became clear that investments in horsecar technology would have to be scrapped, was described as follows (3, pp. 2169-2172):

> Managers of existing street railways and the public alike made the almost fatal error of thinking that the new system of motive power [electricity] contained the possibilities of a gold mine. The promoters [had] dreams of incalculable profits. The whole situation seemed one of amazing

> simplicity and certainty. In place of two horses, requiring the substitution of a new team every four years, and eating as much value of feed every year as their original cost, it was necessary only to place under the old horsecar a permanent electric motor, to build a power station and to erect an overhead wire system consisting of wooden poles and a few wires, in order to move cars at a higher speed and carry more passengers in a more comfortable and attractive manner .... A veritable El Dorado had been attained ....
>
> The first disillusionment of the ... pioneers came with rapid improvements in the art .... Although still mechanically as efficient as when installed, [the original electrical equipment had to be] replaced by ... better equipment costing half again as much [150 percent of original], but ... superior in reliability, flexibility and power ... tracks and the cars must be replaced by entirely new units and heavier units ....
>
> The introduction of the new motive power disclosed almost immediately the desirability of unifying the control of the various previously independent lines in each city .... Horse railways could be operated with as satisfactory financial results in small units as in large ones ....
>
> Notwithstanding the optimism of promoters ..., it was found that the investors in the old and financially established horse railroad companies were reluctant to provide the capital even for the initial change from the old to the new motive power ....

Conservatism in accepting technological change existed even during the beginning of the development of the industry. This conservatism in the industry caused speculators in the new technology to resort to buying out the horsecar owners, thereby piling capitalizations of earlier obsolescent technology on top of the newer debts from modernization—a recurrent theme. This problem of how to absorb obsolescent capitalization will still have to be resolved (most probably in the public sector) if new public transportation technology is to replace still functional (but no longer necessary) conventional transit and taxi technology.

The industry's history is one of great difficulty in handling such technological reinvestment without severe economic disruptions, for example, as in the creation and dissolution of multiple-utility holding companies.

There were also many other abuses, such as heavily watered stock, which led much of the public and many political leaders to mistrust the so-called "transit trusts." This was discussed many times in testimony to the 1919 Commission but was diplomatically avoided in the summary. Much of the lack of public empathy with the industry's problems could be traced to the socially and financially irresponsible image of the companies, which was often justified and constantly fanned by local politicians and newspapers (4, 5).

PUBLIC UTILITY HOLDING COMPANY ACT OF 1935

The critical importance of the public utility holding companies (and the forced divestment of transit operations from them) has been consistently overlooked by analysts of the decline of the transit industry. The most relevant study was the 95-volume, 150,000-page investigation of the power and gas industry made by the Federal Trade Commission (FTC) during 1927 to 1933 (10, 11, 12). Its 1,000-page index does not carry one reference to electric railways or urban transit. The impact of the Public Utility Holding Company Act of 1935, which emanated from FTC and parallel Congressional investigations during the 8 previous years, seems to have been devastating to the transit industry.

The holding companies had played a key role in the provision of capital for electrification of the street railways. The establishment of holding companies that controlled several systems (including power as well as transit utilities) in different localities may have diluted the management interest in its operating properties. To protect their monopoly positions, the utilities had encouraged consumer pressures for public regulation. Though primarily of benefit to investors, the monopolistic position of the holding companies also had some advantages for the general public (3, p. 2174):

> Since the period of greatly increased operating costs ... this advantage of the holding company has been of incalculable benefit to the maintenance of street railway service in many localities. The credit of the holding companies has been placed under the operating companies, and it has been found possible to meet ... the capital requirements of the latter long after their own independent credit has disappeared. ... It not only avoided having all its transportation eggs in one

> basket, but . . . almost without exception, the holding company itself could make a reasonable satisfactory statement of profits through the earnings upon its other classes of investments like gas, light and power, heat and water utilities in which the labor item was of much less importance, and in which bette, conditions of tenure and greater flexibility of rates prevailed, than in the case of street railways.

The FTC study estimated that the power holding companies directly controlled transit operations serving 878.9 million revenue passengers in 1931, about 10 percent of the nationwide total. It also counted about 171 transit companies (about one-fourth of the total) indirectly controlled (via interlocking directorates) by some dozen power trusts. In reality, a retabulation of data by the authors has shown that about 50 percent of the companies and more than 80 percent of the total revenue passengers rode bus and streetcar lines controlled by the holding companies in 1931.

The FTC study and Congressional hearings on the Holding Company Act neglected to consider what effect the proposed legislation would have on the transit industry. The Act's key provision stated that "... after January 1, 1938 ... each registered holding company ... (must) limit (its) operations ... to a single integrated public utility system ...." The SEC could modify this provision slightly where economies of scale were demonstrated, but few holding companies seemed to qualify or want to qualify.

Undoubtedly, because the transit operations of the power companies were showing consistent losses, the power trusts themselves were most anxious to find an excuse to dispose of the properties without incurring the wrath of the local communities with respect to the more profitable franchises. They did not go out of their way to bring up the subject of transit during the hearings or thereafter.

The Act took effect in 1938. Within a few years, only a few large companies were legally left in the hands of the power utilities: New Orleans Public Service and Public Service Transportation of New Jersey (The Transport Company) (13). Some smaller operations are still run by power companies with SEC permission or because no buyer could be found (such as in Columbus, Ohio).

Thus, in a period when most external sources of capital for modernization had totally dried up, the last internal source of aid was withdrawn. Very shortly, the industry would be required to double its output as a result of wartime conditions. This (plus inflation without higher fare structures) was the final blow to many companies in the smaller cities. One must speculate what could have been done with an imaginative federal policy, using the mechanisms of utility holding companies to revitalize transit in exchange for other concessions (as was done locally in New Orleans).

ANTITRUST PROSECUTION OF NATIONAL CITY LINES, GENERAL MOTORS CORPORATION, ET AL.

In 1936, spokesmen for the Yellow Truck and Coach bus-building subsidiary of GMC told Fortune that prospects for the booming bus business appeared excellent (14). Ever since the motor bus had come on the scene in the early 1920s, Yellow had been the leader in sales; its primary job had been to equip the fleets of its own transit companies controlled via its subsidiary, the Hertz Omnibus Corporation.

John D. Hertz had been one of the nation's pioneer taxicab operators. Based in Chicago, using the name of Yellow Cab, Hertz had built and equipped taxi fleets in the days after World War I. To quote Fortune (14) "... Hertz's eyes opened wide to the possibilities of carrying his taxicab ideas one step further and building a bigger motorcar—a bus that would compete with the trolley .... In 1922 he organized the great Chicago Motor Coach Co. out of a bankrupt (jitney) bus line, was even then clutching for control of Fifth Avenue Coach (New York) and People's Motorbus of St. Louis. Great plans of motorizing surface transportation in these cities, of following them up with spectacular bus installations in other first-line cities, were dancing before his eyes. Out of the plans he eventually created Omnibus Corp. ..." Hertz Omnibus Corporation came to control, among the other companies mentioned, the New York Railway holding company through the interlocking directorate between Fifth Avenue Coach and the Interborough Rapid Transit (IRT) Company. New York Omnibus was formed to take over the New York Railway's franchises in Manhattan. After a prolonged battle with the regulatory commissions, New York Omnibus finally won the right to convert the streetcar system during 1935 and 1936. Its massive, successful conversion to motor buses (mostly Yellows) within a period of only 18 months has generally been recognized as the turning point in the electric railway industry in the United States, though it was not until 1940 that industry statistics showed more bus than street railway revenue passengers.

Yellow got into the bus-building business on a large scale when Hertz acquired Fifth Avenue Coach, an early major bus builder and operator. However, Yellow was in desperate need of capital and gained its financial base through an exchange of GMC stock with the Hertz Omnibus Corporation, which gave General Motors control of Yellow's truck, taxicab, and bus manufacturing facilities. The operating properties of the Hertz Omnibus Corporation were not part of the original deal, but there was considerable overlap between the two organizations on the various corporate boards of directors and through stock ownership.

Through a complex series of holding company arrangements, Yellow came to be linked with a new company, NCL, formed in 1936, in time to take advantage of the anticipated narrow SEC interpretations of the 1935 Holding Company Act, slated to become effective in 1938. National City Lines "conceived the idea of purchasing transportation systems in cities where streetcars were no longer practicable and supplanting the latter with passenger buses. Its capital was limited and its earlier experience in public financing convinced it that it could not successfully finance the purchase of an increasing number of operating companies in various parts of the United States by such means. Accordingly it devised a plan of procuring funds from manufacturing companies whose products its operating companies were using . . ." (15).

By 1947, NCL had acquired some 46 transit systems. The acquisitions were financed almost entirely by stock shares sold to GMC, to Firestone Tire and Rubber, and, through the NCL subsidiary, Pacific (later American) City Lines, to Phillips Petroleum, Standard Oil of California, and Mack Manufacturing Corporation.

NCL officials admitted that, with the aid of the GMC engineering department, they had surveyed almost every nonmunicipal major transit company between 1937 and 1940 with the possibility of eventual acquisition in mind. The war had constrained their further expansion, and then the Justice Department intervened.

Curiously, while the nature of these acquisitions were originally shrouded in mystery cloaked by layers of holding companies, this method for modernizing street railway operations had been clearly suggested in the 1936 Fortune article (14). Furthermore, this technique for financing potential customers had been used by General Electric and other vendors of electric railway equipment 30 years earlier. NCL and GMC were convicted of monopolizing the market in the NCL case. It appears, however, that they had played an indispensable role in offsetting the contraction of capital for transit modernization caused by the 1935 Act (16, p. 17).

NCL has since divested itself of most of its operation, through sales to smaller holding companies and public transit authorities. Other former NCL holdings have come under public ownership but are managed on contract by the National City Management Company.

The loss of capital backing from suppliers, coupled with the downward spiral of transit patronage, rendered it unprofitable by the mid-1950s for large bus holding companies to remain in the transit business, which is reminiscent of the situation following the original electrifications a half-century earlier.

Further investigation of the transit industry's complex financial history might well reveal that few, if any, operations ever made large profits from transit operation alone over sustained periods. Strict regulation and other social controls such as political intervention, requiring fares and service to be inflexible, doubtless encouraged numerous illegal or quasi-illegal practices designed to produce income for those performing the entrepreneurial function—no matter what the books reported. Certainly, the opportunities presented by the forced divestiture of many transit operations in the late 1930s and the chance to write off essentially obsolete equipment still carrying high book values appear to have been attractive enough to outside capital to prevent a financial crisis. More recently, private companies again have lacked access to capital. But, the thrust in the 1960s, once the problem was recognized, has been toward public ownership and subsidy, the functional substitute for shady practices of the past.

1955 ANTITRUST COMPLAINT AGAINST GENERAL MOTORS CORPORATION

The antitrust case against GMC was not completely terminated in 1955, despite the District Court's rejection of the government's request for injunctive relief beyond the 1954 consent decree (17). The Justice Department filed a complaint on July 6, 1956, accusing GMC of "illegally monopolizing the manufacture and sale of buses .... The suit also accused General Motors of conspiring with four large bus operating companies to maintain the alleged monopoly ...." Furthermore, GMC maintained the monopoly, the complaint alleged, by "using a financial subsidiary, Yellow Manufacturing Acceptance Corp., to extend preferential financing terms that competitors could not meet; ... inducing officials of municipally-owned transit companies to issue restrictive bus specifications excluding other manufacturers from bidding; (and) ... having a General Motors officer and director serve as board chairman of a principal competitor" (18, p. 8).

The suit noted that between 1925 and 1955 more than twenty manufacturers of buses had withdrawn from the field; no new manufacturer had entered the mass transit bus manufacturing business since 1946. As co-conspirators, the Justice Department named the Hertz Corporation, Greyhound, National City Lines, and Public Service Coordinated Transport.

The case never went to trial. Nine years later, in 1965, GMC signed a consent decree without admitting the substantive allegations of the antitrust complaint.

This agreement is quite restrictive toward the position of GMC in the transit industry. Among other items, the decree states the following (19, pp. 81,802 ff):

1. GMC is enjoined from owning any financial interest in any other manufacturer of buses or any bus operator;
2. GMC must make available parts and technical aid, with certain constraints, to its competitors at the prices quoted for interdivisional billing within the corporation;
3. GMC is to grant royalty-free licenses on patents held and developed since 1965 in the area of mass transit up to 1970 and on a "reasonable" royalty basis to 1975; and
4. GMC has to either establish a competing firm or sell its bus manufacturing facilities if its principal competitor should disappear from the market before 1975 or if GMC should substantially increase its share of the market above the 1964-1965 level by 1975.

The New York Times (20, p. 37) reported that "the small market [only 3,900 buses sold annually] was the key consideration in Justice's decision not to seek the establishment of a new competitor now .... There seemed to be little likelihood that a new company could be successful in today's market .... [The Justice Department officials] said that the market might expand over the next decade, however, particularly in view of the efforts by many cities to improve public transportation systems with Federal assistance. Thus the right to reopen the case was reserved."

TRANSIT REVENUE PASSENGER TRENDS

During the formative days of the electric railway industry, as we noted, per capita ridership rose faster than did the urban population. The introduction of electricity to the horse railways has been offered as the primary explanation for this increase; the higher average speeds and capacity of line-haul electric railways permitted cities to greatly expand their urbanized areas. This dispersion necessitated more transit travel than the compact 19th-century city required. When most people lived within a few miles of their jobs, shopping, and recreational sites during the horsecar days, a considerable diversion from transit riding could be found in walking trips, fluctuating, of course, according to weather and season.

A second major cause for increased per capita ridership—related to the changes of life style brought on by urban spread—was a continual rise in workers' relative wages. Affluence and changing land-use patterns brought a demand for different levels and types of transportation services, too. The conventional transit operators did not (or could not) provide this, but private automobile ownership could; and the automobile, from the post-World War I era to today, took over the role of transit in dictating urbanization patterns.

Figure 1. Trends in transit revenue patronage, 1902 to 1970.

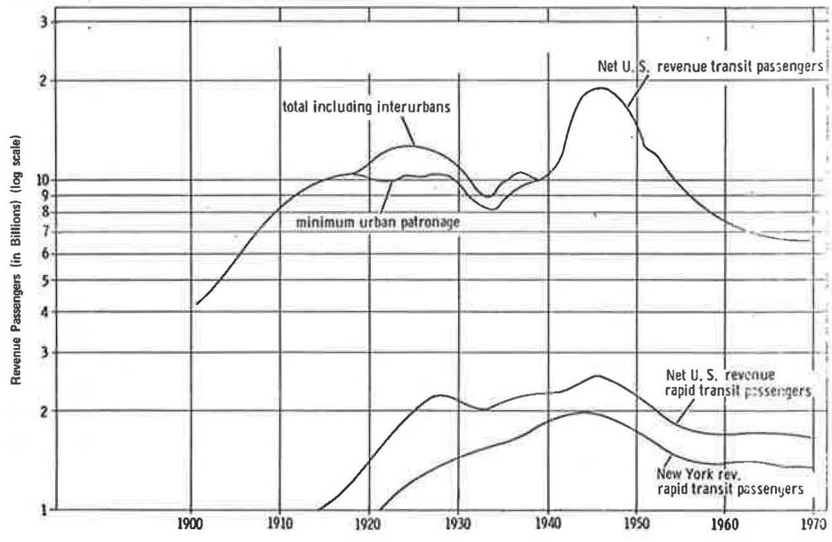


Figure 1 shows, on a logarithmic scale, the trends of revenue ridership from 1902 to 1970 for the U. S. transit industry (2). [Meaningful data on ridership are difficult to obtain and have been poorly presented in past studies. Intercity patronage and lack of standardized accounting for transfer passengers (the definition apparently changed every 5 years) can make as much as a 10 to 20 percent difference in the number of urban revenue passengers. Furthermore, the accounting practices of many companies are somewhat suspect. Few companies made a deliberate effort to count passengers accurately, and, particularly, those who were experimenting with fare structures used imprecise measures of counting based on a guess from the total daily revenue. Statistical sampling to determine passenger load and percentage of transfers was practically unheard of. Double counting has continued to the present day, particularly in New York where a large percentage of the national transit data is collected.] Several points should be noted about these data:

1. Minor fluctuations should be disregarded because they could have been caused by extraneous accounting inaccuracies as well as actual passenger trends.
2. Data have been plotted on semilogarithmic paper to show relative increases and decreases in traffic. Often, figures are presented that show only a tiny portion of the true picture. Almost always they are presented in a linear fashion, which gives the observer the erroneous impression that drastic changes have occurred.
3. Rapid transit patronage trends have been shown separately because their patterns do not follow precisely total transit ridership trends.

Several points should be noted about the trend of ridership:

1. From 1902 to about 1917, ridership more than doubled (from 4 to 10 billion revenue passengers per year) as the street railway industry expanded and took over the former horse railway route structures. A wartime peak may have occurred [a suspicion based on individual company data (21, p. 225)], but it is difficult to substantiate this for the entire industry.
2. Total revenue ridership for the electric railways increased at an even faster rate than previously, from 1917 to 1922, but urban ridership began to level off at about 10 billion per year in about 1921 with imperceptible changes until the beginning of the Depression.
3. Ridership dropped, precipitously perhaps but not drastically compared to the whole, during the worst days of the Depression (1931 to 1933); urban revenue ridership

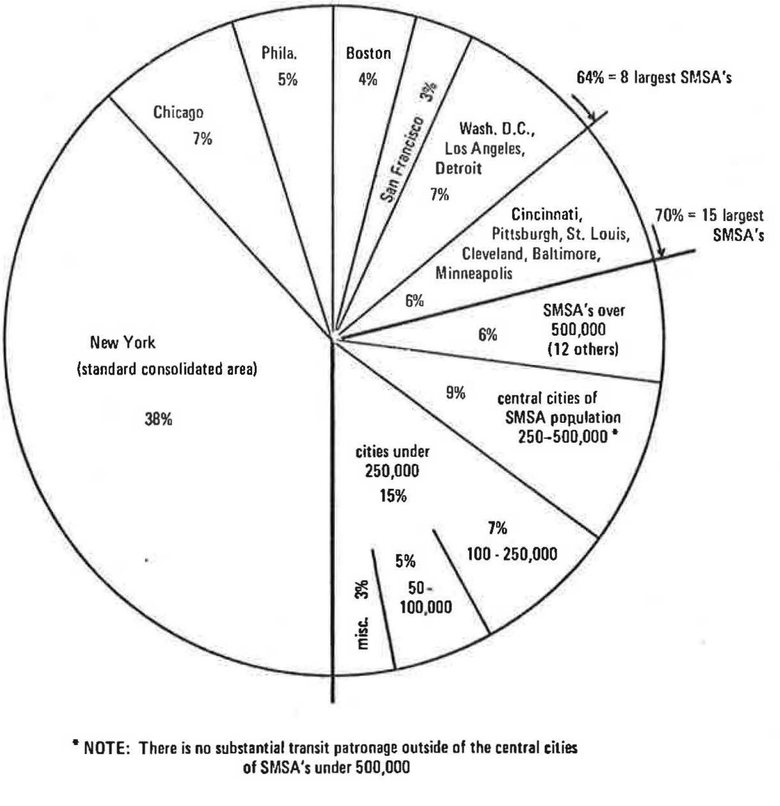
quickly regained momentum after that and appeared to stabilize (at 9 to 10 billion) for a brief period around 1937 to 1940, close to the former 1920 to 1929 levels.

4. During all of this period, the rapid transit component of ridership grew at a slower rate, reaching a stabilization point of about 2 billion in 1927. However, the decline of rapid transit during the Depression was comparatively slight, and in general its ridership has remained much more stable than surface transit. (It must be recognized that New York's percentage of rapid transit ridership has always been about 67 to almost 90 percent of total rapid transit ridership in the United States, and therefore is a bellwether for this total.)

5. During World War II, and for several years thereafter, ridership climbed to about 19 billion, almost twice its prewar level. Gas rationing, wartime industrial production, and automobile parts shortages can more than account for this surge.

Many studies have gone to pains to point out that transit ridership has not kept pace with total trip-making, urban population, and other factors. These theories have been founded on an assumption that conventional transit demand should be a uniform share of the total urban travel market. Schnore (22, pp. 311-323) has shown that transit demand is much more responsive to the higher density living styles found in the older and larger cities than in the newer medium-sized metropolitan areas and suburbs of older cities. Density of population was much less important than age of the city. Indeed, the most rapid declines in transit ridership did occur in the smaller, less dense, and younger cities after the impact of the private automobile. In 1921, 70 percent of U. S. transit ridership took place in cities having populations of less than 1 million (9). By 1930, the ridership in these cities had declined to 50 percent of the U. S. total. The New York metropolitan area currently accounts for about 40 percent of all U. S. revenue transit passengers (it has been within that magnitude for the last 40 years except during

Figure 2. Breakdown of revenue transit passengers by SMSA including bus, rapid transit, and railroad.



* NOTE: There is no substantial transit patronage outside of the central cities of SMSA's under 500,000

World War II). The rapid growth of transit traffic in smaller places during World War II was not shared by New York. This is true for other large cities as well, where the wartime peak accounted for only a minor bump on the curve.

Stratification of 1968 transit passenger data further indicates that the eight largest metropolitan areas account for 64 percent of the U.S. total. Figure 2 shows these relative proportions (data sources include the American Transit Association and private companies). Furthermore, in a sample of four of these cities, where separable data were readily available, the data for suburban versus urban passengers showed that 10 to 20 percent of the passengers were found outside the boundaries of the central cities. If these figures are generally true for other nonmultinucleated large cities, about half of the total revenue passengers for the entire country would be generated within the eight largest central cities. And in New York City, the rapid transit routes alone account for 20 percent of the national total of revenue transit passengers, surface and rapid transit combined.

What are the factors for the general secular decline in transit ridership since the 1920s? There has been almost no attempt in the literature to deal with this, other than in a narrow manner for the past 2 decades only. Several postulates are possible:

1. Transit no longer served the changing needs of the newer portions of the urban population after World War I but remained useful to the older riders for work trips.
2. In particular, transit no longer served the needs of nonwork trips when the automobile became widely available, as evidenced by the data given by Dorau (21, pp. 224-226) applied to Boston:

> During this time [1917-1927], the annual number of revenue passengers remained more or less fixed . . . but the change in character of riding is significant. The number of Sunday and holiday passengers declined about 20 percent. This is to be accounted for by two things–the automobile and the increasing prevalence of summer vacation . . . . Since 1917 . . . there has been an accentuation of the peak hour of the day. This is but another example that the railway service is becoming more and more a business service.

3. If riding had become more of a journey-to-work affair, then the Depression drop would be accounted for by the fact that fewer people were working, especially in the smaller cities.
4. The wartime peak should be dismissed as an aberration, but this seems to have eluded too many transit planners.
5. The wide introduction of the 5-day week can explain much of the drop in ridership by the early 1950s. The widespread introduction of commercial television after 1947 undoubtedly also cut into evening and weekend trip-making. Continuing declines since then could thus mean that the segment of the population dependent on transit is gradually shifting its residential locations and more importantly the transit riding habit is gradually dying off with the riders.

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ANALYSIS AND EVALUATION OF THE RAPID TRANSIT EXTENSION TO CLEVELAND'S AIRPORT

Martin Wohl, The Urban Institute

• DURING the late 1960s, one of Cleveland's two rapid transit lines was extended by slightly more than 4 miles to the airport. Two of the three new stations (including one at the airport) were opened on November 15, 1968, and the third one (Brookpark) was opened on April 20, 1969. The three stations, including the connecting trackage, rights-of-way, and transit cars, were added to the system at a total capital outlay of about $18.4 million. The rolling stock for extension service accounts for $3.4 million of the total. Federal funds covered two-thirds of the total capital costs; the remainder was paid out of city and county funds.

Now, based on 3 full years of actual operating experience, what can be said about the impact of the line on the general public and on users? Also, what inferences can be made about similar proposals in other cities?

It should be emphasized that the analyses, findings, and conclusions of this report are based on limited experience, on sample survey data, and on data collected during years of some rather extraordinary change. As a consequence, they are somewhat tentative, though as complete, accurate, and reasonable as possible.

AIRPORT AND RAPID TRANSIT USE

The small 19-mile Cleveland rapid transit line is owned by the city of Cleveland and includes the airport extension that runs for 4 miles between the Westpark and airport stations. (This does not include the 16-mile Shaker Heights line, which is not part of the city-owned rapid transit system.) The total airport line extends about 11 miles southwesterly from a downtown terminal, the only downtown station, and interconnects not only with the eastern rapid transit line but also with the Shaker Heights system. During 1969, there were approximately 2.5 million passenger enplanements at Hopkins International Airport, about one-fifth the number at Chicago's O'Hare Airport. According to Federal Aviation Administration (FAA) estimates, Hopkins will have 4.8 million in 1975 and 8.1 million in 1980 (1, p. 15). Current figures rank Hopkins Airport as the 18th busiest terminal in the United States, a low figure when compared with Cleveland's position as the 10th largest standard metropolitan statistical area (SMSA) in 1970 population. As given in Table 1, estimated enplanements at Cleveland during 1970 were down about 4 percent from those in 1969 as compared to a national drop of about 1.3 percent.

Passenger volume on the rapid transit system rose during its first 2 full years after the opening of the original 11 stations in 1955 but then fell until two additional stations were opened in 1958. Similarly, after 2 full years of operation, passenger volume again began to decrease on the 15-mile system and steadily declined until 1969, the first full year of operation after the opening of the first two airport extension stations. System ridership decreased sharply during 1970 because of a decrease in air movement, a fare increase, a 17-day transit strike, and continued secular declines. This experience, taken together with that recorded on other North American rapid transit systems, suggests that, in the absence of further extensions (or serious improvements or sizable fare reductions), ridership generally will decrease or, at best, remain fairly level and that decreases in ridership will begin a couple of years following an improve-

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ment or extension. Although these general trends will be offset at least partially by increasing airport usage in future years, they may and probably will be accentuated by increasing affluence and usage of taxis or rental cars.

EFFECT OF EXTENSION ON RAPID TRANSIT RIDERSHIP

The actual ridership data for the Cleveland rapid transit system are shown in Figure 1. Plotted alongside these data are two trend or projection lines that may be used to estimate the extra volumes that resulted from the airport line extension. Without the airport extension, for instance, it could be assumed that the 1969 rapid transit ridership would have remained at the 1968 level, roughly 16.167 million riders. But, with further and normal declines, it would have fallen to a level as low as 15.950 million riders. In turn, the additional ridership attributable to or caused by the airport extension can be estimated as the difference between the actual 1969 ridership (16.490 million) and the two preceding figures. Thus, at the most, we may estimate that the extension increased the 1969 annual passenger volume by about 550,000 and at a minimum by about 350,000. However, because neither of these estimates accounts for the additional riders added in late 1968 (after the November opening of the airport extension) or for the fact that the third station was not opened until mid-April 1969, they should each be increased by about 50,000. The final estimate of increased annual passenger volume as a result of the extension ranges between 400,000 and 600,000 for 1969. (The projection lines shown in Fig. 1 include the joint effects of fare increases and secular declines; admittedly, this makes the 1969 projection estimate somewhat tenuous.)

Although the projection-line technique does have the advantages of being simple and direct, its validity can be questioned. For instance, one may argue that, without the extension, the 5-cent increase that took place in March 1969 would have decreased system patronage more than that indicated by the downward sloping projection line; this argument (which has considerable merit) suggests, then, that the extension resulted in patronage increases higher than the 600,000 figure, during 1969 at least. Moreover, analysis of the data provided (1, Table II-1) suggests that during 1969 the extension resulted in an additional 1.9 million rapid transit riders at the airport station alone. Although this latter figure is somewhat compelling, one nevertheless should keep in mind that this figure is based on comparative before-and-after survey data taken during only 2 weeks, one in September 1968 and the second in September 1969. The "after" data of the second survey probably include some extraordinary riders who were simply testing the system or exploring some of its technical features.

If we consider all of the preceding factors, it seems reasonable to estimate that the airport extension attracted approximately 1 million extra riders during 1969. On the other hand, the 1970 and 1971 passenger decreases for both the system and extension stations (as given in Table 1) lead me to conclude that the extra ridership figure will decline each succeeding year.

Virtually all the analyses, findings, and conclusions given here are based on annual rather than average weekday patronage figures and estimates. By using the former procedure, estimates of both the weekday patronage and the annual expansion factor are simultaneously subjected to scrutiny and tested. Contrarily, studies that simply compare actual and estimated average weekday ridership figures fail to account for any differentials and errors stemming from utilization of inaccurate annual expansion factors and thus can lead to different and sometimes improper conclusions.

Finally, a recent conversation with Cleveland Transit System (CTS) personnel (one occurring after preparation of the bulk of my analysis) suggests that even the 1-million extra-rider figure may be an underestimate. For instance, the CTS research director cited the results of a late 1971, 1-day mail survey that had a 54 percent response rate and that was conducted at the Brookpark and Puritas airport extension stations; 46 percent of the survey respondents said that they were new rapid transit riders. The latter percentage, if assumed to be unbiased with respect to the responses and to weekday-versus-weekend ridership differentials, would suggest that these two airport extension stations alone contributed about 1.26 million extra riders in 1971. Further, the CTS research director said that the CTS had estimated that about 70 percent of the airport station patronage (or about 70 percent of a total of 0.886 million in 1971) were new or extra riders, bringing their estimate of extra riders to a total of 1.88 million in 1971.

Clearly, then, the range of estimates for new riders is wide. Moreover, the problem is even more difficult when trying to estimate the extra ridership figures for future years, regardless of whether the effects of secular declines, future fare increases, and service changes are included. Some attempt at narrowing the gap seems worthwhile (though perhaps daring). The most important statistic suggesting that a lower estimate is closer to the truth is the fact that both the system and airport station patronage fell substantially in 1970 and 1971; airport station patronage dropped more during 1971 because of the surcharge imposed on airport station patrons. These declines, about 20 percent for the airport station in both years and about 14.5 and 5.7 percent in 1970 and 1971 respectively for the system, dwarf the almost negligible decreases in the patronage using the three new airport extension stations. Put together, it would be difficult to argue that the new riders attracted to the rapid transit system are a group that is less affected by fare increases and secular declines than were previous riders; in fact, the contrary would seem closer to the truth.

AIRPORT EXTENSION COSTS

It has been pointed out that the initial capital outlays were about $18.644 million, approximately $3.434 million of which was expended for 20 additional rapid transit cars. Since that time, another $2.5 million has been spent for an additional 10 rapid transit cars for the line. If we assume a 30-year service life for transit cars, a 50-year period for the remaining capital items, and an opportunity cost of 6 percent per year, the annualized debt service for the capital outlays will total approximately $1.4 million a year. (These assumptions probably understate the costs to society because the capital outlays are treated as if they were committed in 1969 rather than in 1966.)

One may examine these data from two perspectives. First, the extra resource expenditures may have been made solely or principally to increase volume. Under this assumption, the additional outlays of $1.4 million per year resulted in an annual increase of 1 million to 1.8 million riders. Thus, there were capital outlays of $0.75 to $1.40 to gain each extra 1969 airport extension rider. In addition, the extra maintenance and operating costs probably range from $0.27 to $0.50 per extra extension rider, bringing the total costs per extra rider to something in the order of $1.02 to $1.90 per trip (2, p. 1). Obviously, these unit costs only apply to 1969 data, and if patronage on the extension continues to decline (as it has even in its early years), these unit costs will increase.

Second, the extra resource expenditures may have been incurred both to increase passenger volume and to improve the services available to former system users. (This accounts for the benefits accruing to former system users who, after the extension was built, switched to a more convenient or accessible station.) If we use this assumption, the extra capital, operating, and maintenance costs can be spread over the total number of riders using the three stations. Thus, the average costs to the general public per trip would be about 50 cents, some 74 percent of which is attributable to capital costs. The application of these two sets of incremental cost calculations will become more apparent in the next section.

FINANCIAL FEASIBILITY OF AIRPORT EXTENSION

Financial as opposed to economic feasibility can be established by determining whether the incremental revenues for the total extension outweigh the extra costs stemming from the improvement and its operation. As noted earlier, the incremental capital costs, when annualized at 6 percent for the estimated service lives, amount to approximately $1.4 million per year. The additional annual operating and maintenance costs are more difficult to obtain because most of the operation and maintenance functions for the extension are not priced separately from those for the total rapid transit system. The preconstruction analysis made by W. C. Gilman and Company estimated that the extension would result in 800,000 extra car-miles per year and an annual increase in maintenance and operating expenses of $0.5 million. [It is difficult to ascertain whether this estimate is either higher or lower than actual extra costs. It was based on an expected total extension patronage that was about 10 percent higher than the actual 1969 and 1970 volume and on a car-mileage figure that apparently was about 7 percent higher than the 1969 amount (1, p. 1; 12). Also, because the maintenance and operation cost estimate was based on 1964 operating cost data for the CTS rapid transit, the estimate was overstated because the extension way and equipment in 1969 and 1970 were newer than that for the CTS rapid transit system in 1964; it was understated because the wage and material costs in 1969 and 1970 were higher than in 1964. Finally, the extra car-mileage and cost estimates were those anticipated for 20 extra cars for the extension, a number that since has been increased to 30.] If this maintenance and operation cost figure is regarded as a reasonable estimate, the total incremental cost will be $1.9 million a year.

Estimating the incremental revenues stemming from the extension is more difficult but can be done reasonably well. However, the extension passenger volume figure (3.7 million a year) definitely should not be used as the basis for the incremental revenue and, in turn, financial feasibility calculations. For instance, those riders who merely shifted from another close-in station to one of the three extension stations obviously did not increase the system revenue total. The obvious exception to this would be shifts to the airport station, which, after November 1970, incurred a 25-cent surcharge. Thus, incremental revenues attributable to the extension resulted only from (a) extra riders (those who were newly attracted to the system as a result of the extension or those riders who otherwise would have stopped using the transit system without the extension) and (b) the surcharge levied on the airport station users.

A simple way of computing the incremental extension revenues would be (a) to multiply the annual 1.00 to 1.88 million extra ridership by the 50-cent basic fare and (b) to add the surcharges obtained at the airport station (overlooking the fact that some airport station patrons pay less than the 25-cent surcharge). [This appears to be a generous way of computing the incremental revenues because the extra-rider figures were based on 1969 data when the (weighted) fare level was about 39 cents rather than 50 cents; even if the extra-rider estimates are considered to hold for 1970 as well, the (weighted) fare for that year was 44 cents, a fare level still below the 50-cent figure.] For the first item, the product would be $0.50 to $0.94 million in extra annual revenues; for the reward item, the total would be equal to about $0.222 million in extra revenues. In sum, the incremental revenues accrued from the airport extension would be equal to a figure between $0.722 and $1.162 million a year, assuming that both of the preceding conditions are valid and that there are no further passenger volume decreases or fare increases.

All things considered, it may be asserted that the airport extension is far less than financially feasible, at least at current fare and service levels. In fact, the extra costs of $1.9 million a year are from 63 to 163 percent higher than the incremental revenues, which at best approach $0.720 to $1.162 million a year.

In addition, it will be helpful to know whether this deficit can be reduced or even eliminated. Definite answers cannot be given to such questions, but some estimates can be made of the financial conditions under different price or fare levels; for this purpose, I will make use of the fare and ridership data at the airport station. For instance, it can be shown that, for the lower pre-1971 fare levels (as given in Table 2), total airport station revenues were less than those occurring after the November 1970 fare increase. (The total revenue levels did not show a consistent increase with fare increases during the 1968 to 1971 period; this variability could have stemmed from various fluctuations in demand, or because of the way in which the "weighted average fare" was computed, or some combination of factors.) Because the price elasticity over the total range of the 35- to 75-cent fare increase was -0.73 (i.e., demand is price-inelastic) and because it has been -0.46 since the November 1970 increase, we can say in general that total revenues can be increased by increasing fare levels and that the fare raises have tended to lessen the financial deficits. (To say that the demand is price-inelastic means that a 1 percent increase in fare will result in less than a 1 percent decrease in passenger volume.) Also, because total costs will decrease as fares increase (because volume levels will drop to some extent), we can say that fare increases will lead to net revenue increases when the demand is price-inelastic. However, to extrapolate either of these two elasticities (-0.73 or -0.46) beyond the range of data on which they were based and especially to suggest that either will apply to even higher fares is not necessarily valid. Put differently, we would like to know which fare change, an increase or a reduction, would increase net revenues and thus reduce financial deficits. If the demand were price-inelastic, as seemingly indicated by the -0.46 elasticity figure accompanying the last fare increase, a further increase might be in order. But because that index represents a rough average for a wide range of fare levels (from 44 to 75 cents), we cannot be entirely certain whether demand is price-inelastic. For instance, if the demand is assumed to be linear and to go through the 1971 data point (Fig. 2), then the demand at the current fare level would be price-elastic, rather than price-inelastic, as indicated by the data given in Table 2. More specifically, the price elasticity at the 1971 data point (for the case of linear demand as shown) would be about -1.05 or higher than unit elasticity. In this case, a small price reduction would increase total revenues, though it would also increase total ridership and total costs; in a similar vein, a price increase would reduce both total revenues and total costs. In both cases, the net could be either positive or negative in contrast to the situation where fares are increased in the inelastic region of the demand function. Thus, in this instance (that is, when the demand is linear and when the fare level is in the elastic region), the analyst cannot ascertain the net effects of a fare change without having more knowledge of the accompanying cost changes. [Specifically, information about the marginal cost function is required. If the marginal cost were reasonably high (relative to the present fare level), a fare increase probably would reduce financial deficits and a reduction would do the opposite. With very low marginal costs, a small fare reduction might improve the financial picture; however, from the standpoint of minimizing deficits or maximizing profits, the fare should not be reduced below the unit elastic point.]

A few final comments seem appropriate with respect to estimates of the change in net revenues stemming from fare changes. First, recall that the previous sets of elasticities were computed solely from airport station data and thus may not be directly applicable to the other two extension stations. In fact, I would judge that airport station patrons tend to be considerably more price-inelastic than other extension riders because so many (about 60 percent) of the airport station patrons are air travelers, a group whose incomes are considerably higher than the usual resident or transit rider. As a consequence, one might suspect that the demand for the two other extension stations at which the fare is only 50 cents per trip is not as price-inelastic as indicated by the data shown in the Figure 2 demand function. Thus, one might also suspect that fare increases above 50 cents for other than airport station patrons would not increase gross and net revenues to the extent that they apparently did for the airport station.

ECONOMIC FEASIBILITY OF THE AIRPORT EXTENSION

To determine economic feasibility, we must ascertain whether the extra benefit or value resulting from the extension outweighs the additional costs. On the benefit side, our attention is not on extra revenues only as it was with the financial feasibility calculations. Here, it is on how much extra benefit or value travelers do obtain from the extension, regardless of whether they pay for that benefit. Put in another way, how much would travelers be willing to pay at a maximum rather than forego the trip or switch to another mode or station? Some travelers would be willing to pay more than others, the exact amounts depending on the trip purpose, on incomes, on preferences, and so forth. Such knowledge depends on accurate estimates of demand for all levels of price and service. Because the available demand data are restricted to only present-day price and service levels, little can be said about the difference between the maximum amount each individual (and the group collectively) would pay and the amount he (and the group) actually does pay. But if the differences were known, it would be possible to estimate the extent to which the incremental benefits are greater than the incremental revenues and thus to determine the economic feasibility of the extension.

From available demand and cost data, one cannot say with any assurance whether the improvement was economically feasible. However, because the incremental costs

Table 1. CTS rapid transit ridership data.

Calendar Year	Total Annual Passengers (millions): New Stations[a]	Airport Station	All Rapid Transit Stations	Total Annual Enplanements at Hopkins Airport (millions)
1968	0.326[b]	0.176[b]	16.167	2.432
1969	3.676	1.400	16.490	2.572
1970[c]	3.668	1.130	14.088	2.475[d]
1971	3.634	0.886	13.288	2.356[d]

Note: The figures for all three new stations and the airport station only were obtained by doubling the actual turnstile counts (outgoing passengers are not counted at individual stations).

[a]Two of the three stations were opened on November 15, 1968; the third was opened April 20, 1969.

[b]These figures were recorded during the 6 weeks following the November 15, 1968, opening date.

[c]The transit system was closed for 17 days during July 1970 because of a strike.

[d]Estimated by the Federal Aviation Administration.

Figure 1. Rapid transit line ridership.

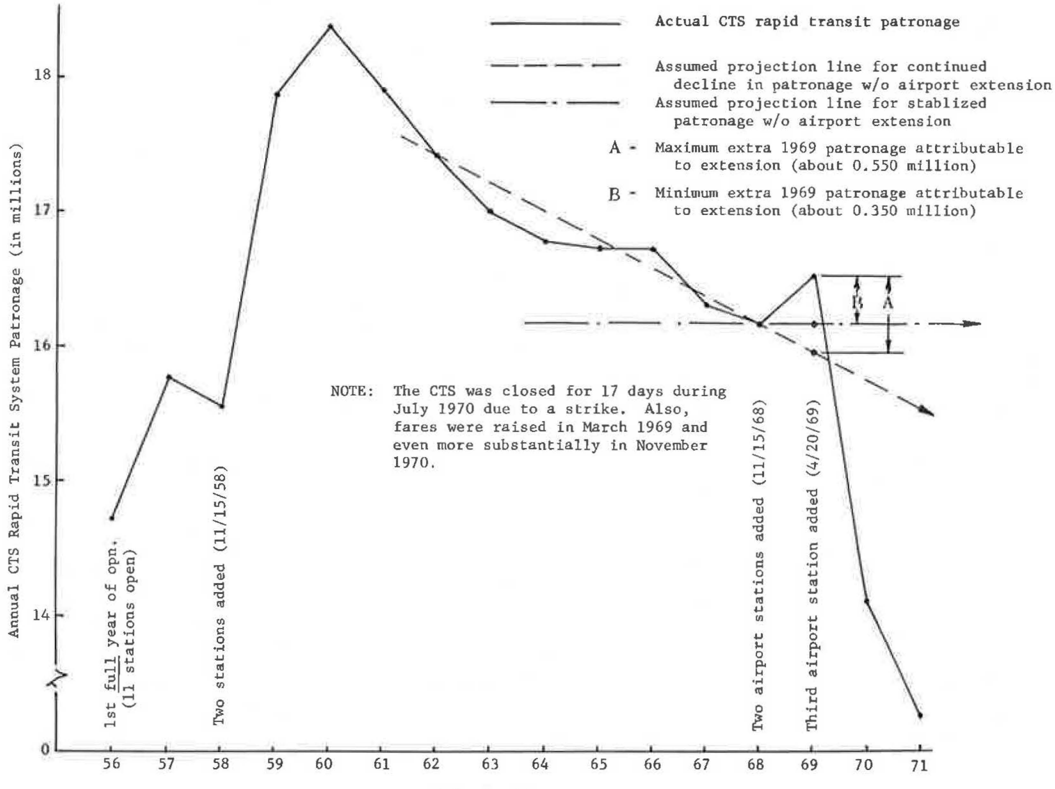

Table 2. Average fare, patronage, and revenue data for airport station.

Calendar Year of Extension Operation	Average Daily Riders Boarding or Alighting at Airport Station[a]	Weighted (by month) Average Fare (cents)	Price Elasticity Over the Range of Fare Increase[b]		Total Annual Revenues From Airport Station (dollars)
1968	4,180	35			534,000
			-0.78		
1969	3,840	39			547,000
			-1.77	-0.73	
1970	3,100[c]	44			498,000
			-0.46		
1971	2,430	75[d]			664,500

Note: Demand is price-inelastic when the elasticity or index is between 0 and -1, unit-elastic when it is exactly -1, and elastic when it is less than -1. When demand is elastic, price reductions will increase total revenue; when demand is inelastic, fare increases will raise total revenue.

[a]The number of extra riders attracted by the total extension is assumed to be equal to these figures; judging from the figures given in Table 1, the assumption appears to be reasonable.

[b]Price elasticity is the percentage of change in volume or patronage accompanying each 1 percent increase in price or fare; in making these computations, the base on which the percentages are computed is the average volume or fare over the range considered. All of the patronage reduction is attributed to just the fare increase (rather than fare increase, secular declines etc.), an assumption that doubtless has led to overestimated price or fare elasticities.

[c]Adjusted to account for effect of strike.

[d]This figure does not include reduced rate surcharge passes.

of the extension are from 63 to 163 percent higher than the incremental revenues, some doubt must be expressed whether current riders find the service so attractive that they would rather pay the difference than forego the service. At one extreme, we can ask the following question: Would each "average" extension rider (a composite of new riders and former riders who merely switched from closer-in stations) pay an extra 20 to 32 cents (over and above current fares) rather than give up the extra benefits? At the other extreme, we can assume that the extra benefits received by former riders who merely switched from closer-in to farther-out airport extension stations are so small that the riders would be unwilling to pay very much extra for this improved service. (The data given in Table 1 tend to support this assumption. For instance, the volume of total patronage at the three extension stations remained reasonably steady following the implementation of the system-wide November 1970 fare increase and the airport station surcharge, whereas ridership at the airport station fell considerably; this indicates that those who shifted to the airport station from closer in stations prior to November 1970 and then shifted back to closer in stations afterwards found the extra benefit worth less than 25 cents.) This implies that virtually all the extra benefits are received by new riders. If we adopt this assumption and use the annual 1.00 to 1.88 million extra ridership estimate, it can be seen that the airport extension would be economically feasible only if the new riders are willing to pay from 74 to 190 percent more than the current fare, or from $1.00 to $1.90 more per trip, on the average, rather than forego the service. This seems unlikely, and thus it is difficult to conclude that the airport extension is economically feasible, even when "consumers' surpluses" for current riders are incorporated.

Importantly, though, this conclusion is partially dependent on current fare and patronage levels, both of which affect the costs and benefits resulting from the extension. Other fare levels, for example, may result in larger net benefits and thus improve the chances for economic feasibility. It is almost impossible to assess the effects of different fare levels, however, without having information about the costs of the levels of usage of the extension. Should the current fare be higher than the marginal cost (for the current volume level), then the conditions for economic feasibility will be enhanced by reducing the fare until it just equals the marginal cost (3). Contrarily, when the marginal cost is higher than the fare, a fare hike would improve the chances for economic feasibility. But, unfortunately, there is no way of knowing which of these conditions now exists for the Hopkins extension.

Also, what might be learned from alternative travel mode data for extension riders at the airport station? Most new airport station riders shifted primarily from limousine usage (about 700 per day) or from private automobile usage (about 600 per day) and secondarily from taxi usage (just more than 300 per day) (1, Table III-15). These shifts represented a 50 percent decrease in limousine ridership, a 25 percent decrease in taxi patronage, and an 8 percent drop in private automobile usage. The decrease in limousine usage seems most understandable because most of the trips started or ended in the downtown area, the service was not particularly preferable to that of the rapid transit system, and the $1.60 downtown-to-airport limousine ride was about four times more costly than a similar rapid transit ride. Further, it does not seem strange that the percentage of decrease in taxi usage was less than that for the limousine. If taxi riders had been especially concerned about the high cost of cabs (about $6 to $7 from downtown to the airport), more would have used limousines previously. Even so, it is obvious that, by adding a dollar to the differential between the taxi and the alternative public mode fares, some riders were induced to make the switch. The third group, those switching from the automobile, mostly included residents of well-to-do communities that are east of Cleveland's downtown and have easy access to rapid transit stations. Prior to the extension, these people simply did not have either a reasonably priced or a convenient alternative to the automobile.

Finally, it should be noted that analyses that fully incorporate consumers' surpluses into incremental benefit totals will thereby take full account of the value of travel time savings and such other benefits accruing to transit users. However, such benefits as time savings accruing to highway users as a result of reduced congestion (when some former highway users shifted to the airport extension) can be regarded as external benefits and should be included in the incremental benefit totals in addition to the other aspects mentioned. Some estimates of the magnitude of these external benefits are provided in the following sections.

EXTERNAL BENEFITS AND COSTS

The Hopkins extension has had other impacts, both positive and negative. Among the more obvious are revenue losses for bus, limousine, and taxi operators, at least some (if not all) of which can be offset by reductions in operating and possibly capital costs stemming from smaller passenger loads and reduced frequency; the loss in traveler benefits for former bus, limousine, and taxi patrons; worse service for the remaining bus and limousine users due to reduced schedules; increased noise for firms and residents abutting the transit extension; reduced congestion, air, and noise pollution; "windfall" gains for some owners of close-by property; and social (or economic) disruption for some of those displaced or inconvenienced by the extension and its parking lots. (Some analysts have suggested that the financial and economic feasibility analyses given earlier should have included the bus, limousine, and taxi cost savings as financial and economic gains stemming from the extension; however, this would not be correct unless we also took account of the concomitant reductions in revenues and traveler benefits, and so forth.)

In a similar vein, airport extension riders enjoy a higher quality and more accessible rapid transit service, but one that is subsidized. Most of the capital outlays are funded out of city, county, and federal revenue sources rather than charged to the riders because the incremental revenues cover operating costs and only 16 to 46 percent of the remaining capital outlays. It seems appropriate, then, to ask who the riders are, at least in terms of income characteristics, and to compare them with others in the Cleveland area. (Obviously, this comparison does not account for tax transfers.) Table 3 summarizes the few data that are available on this score. It is apparent that the airport station riders who make use of the extension are, as a group, considerably more affluent than the average Cleveland citizen (4, 5). This is especially true, of course, for the passengers who ride the line and who constitute almost 60 percent of the airport station patrons and about 20 percent of all extension riders. Although these few data permit no definitive answers, they do suggest that subsidization of the Hopkins extension represents an income transfer from poor to well-to-do citizens.

EFFECT ON TRAFFIC CONGESTION

Another aspect given prominent attention when discussions of airport extensions take place is that of the reduction of traffic congestion when automobile drivers are diverted to transit facilities. Although no exact measures of the effect of the Hopkins extension are available, some approximations can be made and should be helpful to such an assessment.

As noted earlier, only 1.00 to 1.88 million riders of the 4 million annual extension riders represent additional CTS riders; the others merely shifted from closer-in to one of the three new extension stations. The congestion reduction from those shifting from one transit station to another is probably small because the traffic movement takes place some 7 to 11 miles from the central business district. Clearly, those shifting from other modes to the transit extension are the much more significant group. For the analysis of traffic congestion as affected by the extension, the following assumption will be made: Because the 1969 airport station patronage was 1.4 million, or about 0.8 million higher than anticipated, it will be assumed that virtually all new riders who were using the extension in 1969 (prior to the 1970 fare increase and airport station surcharge) got on and off at the airport station. Thus, inferences about former modal choices and so forth can be made from the data given in another report (1, Tables III-15, IV-24, V-18, VI-1), which deals only with airport station riders.

In calculating the modal shifts and the resultant reduction in highway travel, we will deal with air passengers, air passenger-related visitors, employees, and casual visitors separately. It is doubtful that the extension led to any extra air travel. Finally, it will be assumed that the 1969 air passengers who did use the transit extension would have made the same modal choices without the airport extension as did the 1968 trip-

Figure 2. Price elasticity of rapid transit line.

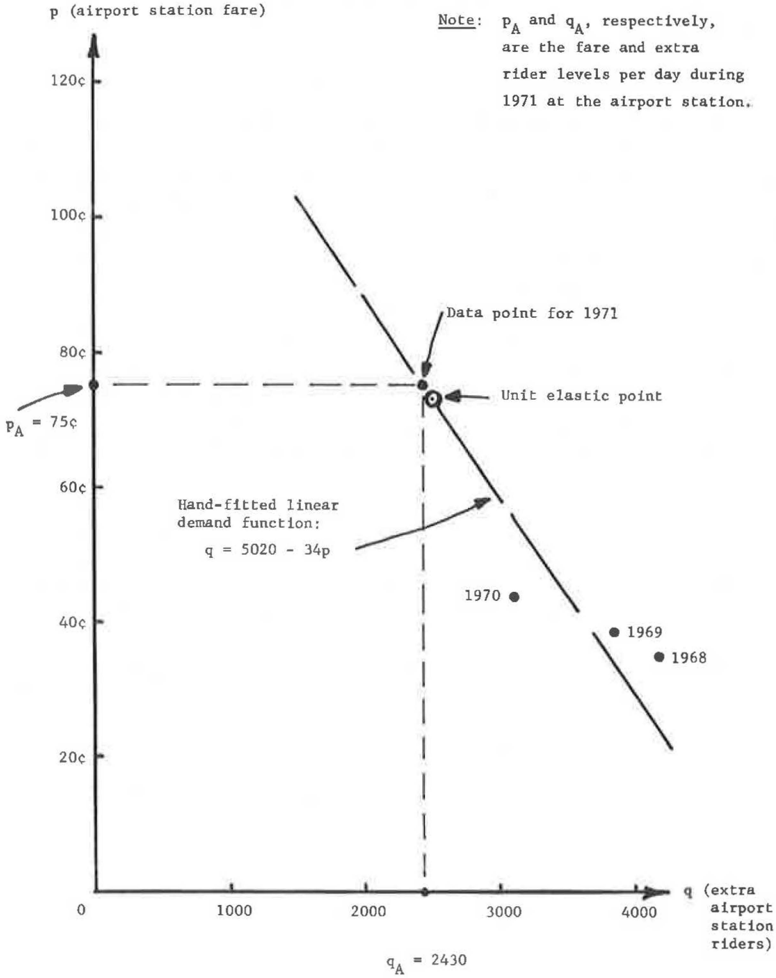

Table 3. Family income characteristics of extension riders.

Family Income (dollars)	Hopkins Airport Station Rapid Transit Riders[a] (percent)			Cleveland SMSA Families
	Air Travelers[b]	Travelers' Visitors[c]	Casual Visitors[d]	
Less than 5,000	4.1	9.6	19.0	NA
5,000 to 10,000	13.1	19.4	33.0	NA
10,000 to 15,000	21.6	31.0	30.0	NA
More than 15,000	61.2	40.0	18.0	NA

Note: The 1969 estimated median family income for air travelers is $16,400; for travelers' visitors it is $13,400; for casual visitors it is $9,700; and for Cleveland SMSA families it is $11,000.

[a]For all these riders, who made up about 85 percent of the airport station rapid transit riders in September 1969, the (weighted) median family income is estimated as $14,700 (1, Tables III-5, IV-9, VI-10). No data were available for employees using the airport station (who represent 14.9 percent of the rapid transit passengers boarding or alighting at the airport station).

[b]This group makes up about 57.6 percent of the rapid transit passengers boarding or alighting at the airport station. Also, 39.9 percent of this group has family incomes of $20,000 or more.

[c]This group makes up about 10.5 percent of the rapid transit passengers boarding or alighting at the airport station.

[d]This group makes up about 17.0 percent of the rapid transit passengers boarding or alighting at the airport station.

makers before the extension opened. Following these assumptions, it can be shown that the maximum daily reduction in private car and taxi trips has been 7,000 and that there have been almost 1,300 fewer public bus person trips per day and just over 5,000 fewer bus-limousine person trips per day (1, Table III-15). It is doubtful, though, that the reduction in bus and bus-limousine person trips led to a significant reduction in vehicular trips. To determine the reduction in congestion, especially rush-hour congestion, we must convert these daily vehicular trip figures to hourly figures by using peaking factors. Peaking for air travelers is generally less than that for other transport groups, and the percentage of the daily Cleveland air passenger trips made during the peak hour (5 to 6 p.m.) ranges from 12 to 14 percent (1, Table III-10). As a consequence, approximately 1,000 vehicular trips may have been removed from the surrounding roads and streets during the peak hour. As many as 700 vehicles per hour may have been taken off the highways during two other hours (one of which is during the morning rush period), but during most of the daylight hours fewer than 500 an hour would have been removed.

Similar calculations for passenger-related visitors, for casual visitors, and for employees reveal that the extension caused no decrease in the number of private automobile trips for casual visitors but led to increased casual trip-making to the airport, most of which took place by rapid transit (1, Table V-1). Also, the extension reduced the number of private automobile trips made by passenger-related visitors by some 1,500 trips a day (1, Table IV-24). Because these visitors follow the same peaking pattern as air passengers, there are at most only 200 fewer vehicular trips made on the adjoining roads and streets during the peak hour and fewer than 100 an hour during most hours of the day. Also, approximately 200 fewer employees made private automobile and taxi trips to and from work, thus reducing automobile trips by the same number (at a maximum) during the peak hour for air passengers.

In total, then, it may be estimated that, during the peak hour, no more than 1,400 automobiles and taxis and fewer than 100 buses and limousines were removed from adjoining roads and streets as a result of the extension. However, given the diversity of origins and destinations of these three groups, it is very difficult to estimate how much this reduced traffic congestion. The wide variety of origins and destinations for air passenger trips, which would constitute the bulk of vehicular trip reductions, is given elsewhere (1). It would be most helpful to know how many of these trips were diverted from the downtown and more congested end of I-71, an expressway that roughly parallels the airport extension and the west-side rapid transit line (1). As an approximation, it could be estimated that at most no more than 2,500 (or 35 percent) of the 7,000 fewer air passenger automobile trips made daily would have made use of the expressway if the extension had not been built. This assumes that almost 80 percent of the air passengers who have Cuyahoga origins or destinations (or about 50 percent of all air passengers) would have used the expressway if the extension had not been built. By combining these data with those for passenger-related and casual visitors, we can estimate that evening peak-hour traffic on the expressway has been reduced by some 500 vehicles an hour. Most of this traffic moves in the outbound or major flow direction during the 5 to 6 p.m. peak hour. At the downtown end of the expressway, where there are four lanes in each direction, there will be some reduction in congestion but hardly a major amount because the total flow is reduced at most by 125 vehicles per lane per hour. This reduction, however, is less than 10 percent of the current rush-period volume levels on this roadway, which range from 1,500 to 2,000 vehicles per lane per hour. Thus, the peak-hour speeds may have been increased by a couple of miles per hour for this section of the expressway, saving no more than ½ minute per trip (6). At the airport end of the expressway, where there are only three lanes in each direction but much smaller total flows, the reduced volumes of about 170 vehicles per lane per hour will have little effect. The per-lane peak-hour flows, approximately 1,200 to 1,300 vehicles, are currently well below critical levels.

Under the best of conditions and most liberal assumptions, then, it is difficult to attribute any significant gains in reduced congestion and pollution to the airport extension. Small increases in speed and reductions in congestion and pollution have been achieved, but even these are limited to 2 or 3 hours a day (with the maximum effect occurring during the 5 to 6 p.m. peak hour). These external benefits may be considered as offsetting some of the apparent economic and financial deficits enumerated earlier, though it is difficult to believe that these external benefits could constitute a major consideration.

IMPLICATIONS FOR OTHER AIRPORT EXTENSIONS

What are the implications of the Cleveland extension for other cities? To begin, in Cleveland the airport is responsible for only a small portion of the rapid transit patronage and the extension volume. Although airport passengers, visitors, and employees using the rapid transit extension represent about 92 percent of the airport station's patrons, this same group of airport users totals only 35 percent of the extension's users and less than 8 percent of the rapid transit patronage. Moreover, the new riders attracted by the extension, most of whom are air passengers who formerly traveled to the airport by other modes, represent only 7 to 14 percent of the total rapid transit system patronage.

Several reasons account for low utilization of the Cleveland airport extension. One, Hopkins is not a heavily used airport; at least 17 other U. S. airports currently have heavier patronage. Chicago's O'Hare, the busiest airport, has approximately 5 times more passenger enplanements, Kennedy has about 4½ times as many, and Los Angeles has about 4 times as many (7). Two, for a city of its size and density, the Hopkins International Airport is located a great distance from the city center. For instance, Hopkins is roughly the same distance from downtown, 14 miles, as are the New York Kennedy, San Francisco, and Los Angeles airports and only 3½ miles less than O'Hare is from downtown Chicago (8). Also, peak volumes, for airports generally and for Cleveland particularly, are low when compared with the high passenger-carrying capacity of rapid transit lines. In 1970, for example, O'Hare had approximately 12,000 passengers (by all modes) during its peak hour; Kennedy about 10,000; Los Angeles about 9,000; and Cleveland only 2,800. Finally, for Cleveland (and elsewhere) the origins or destinations of the airport passengers, visitors, and employees are diverse and not concentrated in the central business district (1, p. 38). At best, only 30 to 40 percent of air passenger travel moves to or from the downtown in most cities, except in New York where approximately 45 percent of current air travelers move to or from Manhattan. Because fixed rail rapid transit facilities rarely provide adequate service to other than close-in downtown areas, the potential passenger volume for fixed rail facilities is quite low—currently some 5,000 passengers maximum during the peak hour at the largest U. S. airport. (Even this figure, and certainly not Cleveland's 2,800, is insignificant when compared with rail transit capacities that can exceed 40,000 an hour.)

Cleveland is atypical in two major respects. First, Cleveland has a small downtown area, and only 10 percent of its air passengers start or finish their trips in the central business district (1, p. 30). This percentage is far lower than that experienced by New York, Chicago, Washington, Boston, and San Francisco even though they have no direct airport extension. This suggests, then, that extensions in other cities would fare better than Cleveland's. Second, Cleveland probably can better serve other-than-downtown travelers. One unique feature of Cleveland's system is that it has increased its utility and patronage beyond that which could be anticipated in other cities. The areas generating most resident-made air travel are directly connected to the airport by the CTS and Shaker Heights rapid transit lines, are east of the downtown core, are laid out on an east-west axis, require long and arduous cross-town trips, and thus are well served by the east-west rapid transit lines. Shaker Heights, Cleveland Heights, University Heights, East Cleveland, and University Circle, for example, generate heavy air travel and lie on a straight-line path that requires a lengthy and congested 15-mile trip through the central core of the city to the airport. As a result, people living in such areas can avoid the long and uncomfortable downtown trip by car. They can get to the airport directly by taking the rapid transit line and can avoid airport parking charges. (These may be offset, at least partially, by parking fees or feeder service costs at the other end of the trip.) And they do make heavy use of the service (relative to most other residents).

Only 29 percent of the air passengers having a Cleveland (central city) origin or destination, the area having highest density and closest proximity to most stations, use the airport extension. This figure compares with 52 percent in East Cleveland, 46 percent in Cleveland Heights, 35 percent in University Heights, 32 percent in South Euclid, and 25 percent in Shaker Heights. The communities are all more distant from the airport than is the Cleveland central city area and have many well-to-do residents that are directly served by rapid transit service. By contrast, it seems doubtful that the New York and Chicago airport extensions, for example, would be able to serve adequately more than a handful of trips having other than strictly downtown origins or destinations. For instance, travelers not bound for or coming from downtown would have to gain access to the facility at the originating end of the trip, travel downtown, and then transfer to another outbound line to reach their destination, making a very circuitous, inconvenient, and time-consuming trip. Most bedroom communities in these and other large cities would not be on a direct and fairly straight rapid transit route with an extension to the airport and thus would be worse off than Cleveland in this respect.

CONCLUSIONS

All things considered, can the Hopkins Airport extension be described as a success or as a failure?

According to some proponents, it is a success. For instance, Secretary Volpe (9) in speaking for the Department of Transportation, the principal funding agency for the Hopkins extension, said that "Cleveland's experience with its airport-to-downtown rail rapid transit link over the past 2 years has been very heartening," and he generally seemed to indicate that the extension had been a success. Subsequently, a newspaper article (10) exaggerated the comments of Secretary Volpe by stating that "The Department of Transportation reports that the results of a study published October 8 show that Cleveland's airport-to-downtown airport service has proved to be an unqualified success." And, not too surprisingly, the Cleveland Transit System General Manager, in a New York Times interview, summed up his views about the extension by saying it is very successful.

However, in view of these data, findings, and considerations, one must wonder about the validity of these or other such unconditional endorsements.

First, the incremental costs for the extension are from 63 to 163 percent greater than the incremental revenues received from its new riders and from the airport surcharge, the deficit being in the range of \$0.738 to \$1.178 million a year for current fare levels and volumes. At present, then, the extension must be regarded as a distinct financial failure. Not only that, but there seems little hope for significantly reducing, much less eliminating, the deficits resulting from the extension. For instance, the earlier analysis indicated that the current fare demand is (probably) slightly price-elastic and that deficit reductions can be accomplished (if at all) only by utilizing a monopolistic pricing policy. But even monopolistic prices would do little to decrease the deficit if the marginal costs (i.e., the extra costs incurred to handle an extra extension passenger) are quite low or at least substantially lower than the current average variable costs. For volume levels and load factors as low as those on the Hopkins extension, the marginal costs probably are low (both absolutely and relative to average variable costs). Thus, one might conclude that the deficits are about as low as is possible.

Second, the extension appears to be economically as well as financially infeasible. Put differently, even if consumers' surpluses (that is, the amounts current riders would be willing to pay over and above what they now pay rather than switch to other modes or forego trips) were added to their revenues and if the total was balanced against the extra costs, there seems to be little chance that the total would be high enough to "tip the scales." As noted earlier, the "average" patron would have to be willing to pay an extra 20 to 32 cents; put differently, each rider would have to pay a fare that is almost 40 to 60 percent higher than the current one (without switching modes or foregoing the trip) in order for the consumers' surpluses to outweigh the current deficits. This appears to be an unlikely possibility, especially because fares on the CTS transit lines are already very high (compared to other rapid transit lines).

Third, although slightly more than 2,000 air passengers (about 14 percent of Hopkins' air passengers) and about 10,000 passengers in total use the extension daily, these can hardly be regarded as significantly large volumes—certainly not, at least, for a high-capacity rail rapid transit line. Nor can the diversion of even as many as 3,000 passengers a day from automobiles be considered a significant (if even measurable) reduction in traffic congestion; realistically, only a small reduction in congestion has resulted from the extension because, at best, only 125 vehicles have been removed from each lane of the most congested Cleveland expressway during the peak hour. If, moreover, we consider the fact that this subsidized airport extension is heavily used by people considerably more affluent than most Cleveland residents, some doubt must be raised about the extension's success when judged on equity or "fairness" grounds.

There are two final points I would like to make. One, the Cleveland experience underlines the importance of conducting good feasibility studies in advance of such improvement programs. These studies should be comprehensive, incorporating both financial and economic feasibility analyses. They should analyze the sensitivity of the ridership to different fare levels and service conditions. Such preliminary investigations should do more than "talk about" supposed congestion and pollution reduction; they should consider as well the effect of such programs on the citizens involved. Further, it is necessary not only to look at the potential users, and the source of any subsidies to them, but also to consider whether it is equitable to extend a transit line with public funds without compensating private taxi and limousine operators and others for any losses they may sustain as a result. Two, it appears that rapid transit extensions to airports are not "the" answer to ground access problems and will not generate massive or even moderately heavy usage (11). To the contrary, large capital outlays will be required in order to finance a premium service to be used heavily, if not mainly, by a small number of very well-to-do urban air travelers.

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ANALYSIS OF USER PREFERENCES FOR SYSTEM CHARACTERISTICS TO CAUSE A MODAL SHIFT

Gerald R. Brown, University of British Columbia, Canada

This study is an investigation of the use of subjective preferences to complement behavioral observations as a means of determining the propensity, or tendency, of an individual automobile driver to shift to a new mode. A so-called propensity model of the discrimination-classification type is formulated from individual preferences for the performance characteristics required to encourage a shift to a multimodal park-and-ride type of transportation system or, conversely, a change in downtown parking cost to effect a shift to bus transit. The propensity model indicates that a substantial shift could be brought about by relatively small decreases in overall travel time, provided that walk times in parking terminals are about 2 min or less and transit line-haul frequency is $4\frac{1}{2}$ min or less. Parking charges were found to be an effective instrument to create a shift to bus transit. The validity of the preference-based model is tested by analyzing the degree to which stated preferences are independent of existing service levels. The test shows that respondent preferences for travel time and parking costs were not radically different from those existing but that walk times and transit frequency for a new mode must be radically different. It is concluded that subjective preferences are useful to study travel mode diversion but that better subjective surveys and means of controlling and monitoring changes in modal split with changes in policy-related variables are needed.

•THE trend in modal-choice analysis is toward the use of behavioral models that treat modal choice as a function of the performance characteristics of a transportation system. Behavior models structured in policy terms allow us to study and plan a socially desirable modal split by using simulation methods. This approach, if it is to be successful when applied to modal-split planning, requires that behavioral data be available for all combinations and ranges of transit service and that the model be structured in terms of those instrument variables that have maximum user sensitivity. Because existing transit usage may be constrained by the lack of some of the attributes deemed desirable by potential new users, behavioral data by themselves may lessen the predictive ability of the model if a new mode, consisting of radically different performance levels, is introduced. One way of overcoming this limitation is to model a user's subjective evaluation of the attributes of any mode to find the relative importance of the attributes introduced in a new mode. Inferences can then be made from the subjective attitudes about future usage on the new mode, if implemented. If the variables used in the evaluation are instrumental ones, modal-split planning can be carried out by changing the value of the variables in the model to simulate policy options for the community.

The present study explores the feasibility of a modal-split planning model based on the stated preferences of automobile commuters for those system attributes that would encourage a modal shift. Specifically, the objectives of the study are to discuss a method, based on the use of subjective preferences, that might be useful to study the diversion of commuters to a multimodal park-and-ride system and to find the relative importance of each of the attributes of the system in causing a modal shift.

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RECENT ADVANCES IN MODAL-CHOICE RESEARCH

Two major recent advances in modal-choice research have been the abstract mode concept, in which a mode is defined by its performance attributes and the relative utility of these attributes for the individual trip-maker, and the use of attitudinal and opinion surveys to derive subjective measurement of modal attributes.

The abstract mode concept is based on Lancaster's thesis that it is the intrinsic properties of a good that give satisfaction, not the good per se (1). Quandt and Baumol (2) applied this thesis to modal choice and conceptualized a transportation mode as a bundle of attributes characterized by its performance dimensions (such as travel time, travel cost, and frequency of service). Several models that use abstract mode attributes and the utilitarian concept that an individual seeks to maximize his satisfactions (or minimize his dissatisfactions) have been formulated. Ackoff's diversion model (3) is based on the idea that an individual will switch from his usual mode to the best alternative when changes in the perceived differences between the attributes of the usual mode and the alternative reach a certain point. Quarmby (4) conceived of travel dimensions which give rise to disutility of travel. He was able to study a planned shift by simulating new variable values, thereby making the alternative assume a lower disutility than the usual mode. Pratt (5) and McGillivray (6) provide similar analyses.

Several studies have used subjective measurements of modal performance characteristics in modal-choice research. Ackoff (3) scaled travel-time and travel-cost attributes to determine at what point a respondent would switch modes. Wachs (7) studied the subjective evaluation of a transportation system by using an opinion survey. Nash and Hill (8) used factor analysis to determine the most important subjective attributes of an ideal transportation system. Golob (9) studied the relative satisfaction of the users with the first and second choices of mode; Sommers (10) studied relative satisfaction and the acceptability of a hypothetical mode.

OUTLINE OF A SHIFT PROPENSITY MODEL

The present study uses stated preferences to model the propensity of an individual to shift to a new mode. The model is called a propensity model because prediction of behavior from stated preferences for modal attributes is only possible if those who say they will shift (provided their preferences are met) actually do so if the system is changed. Given the state of the art, the most we can assert is that any individual will have some tendency to act in accordance with his stated preferences. The concept assumes that there is some level of service of the new mode at which rational automobile drivers will shift because the perceived disutility becomes equal to or drops below that of driving. Consequently, the individual whose stated preference pattern is met by the new combination of attributes will have some propensity to shift modes.

It is assumed that each user chooses the mode that he perceives to have the least disutility of all modes available to him. Also, it is assumed that a user's perception of a mode is in terms of its intrinsic characteristics, or attributes, and not of its institutionalized nature (e.g., bus, rail rapid, or automobile). If we further assume that the total disutility of a mode is linear and is an additive function of its attributes as perceived by any user k, we can state, after Golob (9), that the decision to take a particular mode is because

$$U_k^1 < U_k^2$$

where

U_k^1 = total disutility of accepted mode (i.e., mode 1), and
U_k^2 = total disutility of rejected mode (i.e., mode 2).

But each mode is an abstraction of some combination of modal attributes so that

$$\sum_{i=1}^{p} U_{i,k}^1 < \sum_{i=1}^{p} U_{i,k}^2 \tag{1}$$

where

$U^j_{i,k}$ = disutility of attribute i for mode j as perceived by user k, and
p = total number of attributes considered in the choice decision.

Each disutility term $U^j_{i,k}$ can be conceived to consist of two components: a parameter that is a variable measure of the attribute and a parameter that weighs that attribute in relation to all other attributes considered with respect to the relative value placed on the attribute in the modal-choice decision. Therefore, the disutility of any attribute is the product of a weighting coefficient and the number of units of the attribute experienced, or

$$U^j_{i,k} = V_i X^j_{i,k} \tag{2}$$

where

V_i = value user k places on attribute i, and
$X^j_{i,k}$ = measure of attribute i of mode j as perceived by user k.

Consequently, mode 1 is accepted and mode 2 is rejected when

$$\sum_{i=1}^{p} V_i X^1_{i,k} < \sum_{i=1}^{p} V_i X^2_{i,k}$$

or when

$$\sum_{i=1}^{p} V_i (X^1_{i,k} - X^2_{i,k}) < 0 \tag{3}$$

Several aspects of this function are noteworthy. First, the function is described in terms of relative disutilities of two alternatives (i.e., a binary choice problem). The function has been derived here by using differences between attributes of the two modes, but the form of the inequality remains the same if ratios are used (i.e., the right-hand side would be < 1 for ratios, rather than < 0). Second, the function applies only to a single individual. Individual utilities are not comparable. That is, the function describes the relative disutilities of each attribute for the modal-choice decision, but the strength of acceptance of a mode by an individual cannot be compared with the strength of another individual's acceptance. Because of this, individual disutilities are not additive. However, if the vectors **X** are treated as random vectors, a probability distribution can be determined that will be a statistical description of the aggregation of individual k, where k = 1, N. Third, note that disutility is described in terms of perceived differences between modal attributes. Utility (disutility) is purely subjective and depends on subjective values for the variables of the disutility function. One disadvantage of this approach is the possible interdependence between the subjective measure given through interview of the system attributes and the psychological value attached to that attribute. That is, if an individual places great value on travel time, he may overestimate his actual travel time to work (i.e., by objective measurements). There may also be some intercorrelation between the existing level of service and the subjective evaluation of ideal levels of service preferred. These problems are discussed later.

The shift propensity scheme may be outlined in terms of indifference curve analysis using stated preferences as follows.

Consider I_k, I_k, the indifference curve for individual k, which is the locus of all combinations of two system attributes (e.g., overall travel time and overall travel cost) as shown in Figure 1. The curve describes an individual's preferences within the context of his budget constraints and the modes available to him. U^1_k is the point at which the time-cost combination gives him least dissatisfaction and therefore represents the disutility of the characteristics of mode used (if we assume the modal attributes are continuous). On the other hand, U^2_k represents the characteristics of the mode rejected and is always to the right of I_k, I_k because the disutility of this combination is greater than that of the mode used. However, the characteristics of U_k^2 can be changed in such a way that individual k will be indifferent to whether he continues to use the existing mode or shifts to the alternative. This point is shown at U_k^3, which in this example results from decreasing the cost of the alternative.

The relative attribute values X of U_k^3 to U_k^1 define a relative disutility function for the individual and describe his propensity to shift modes. These relative values can then be plotted in two-dimensional space (using time and cost attributes), which represents the location of that individual vis-à-vis all other individuals. Assume that U_k^1 represents (for these two attributes) the cluster of disutility measures for a sample of individuals who drive to work and that U_k^3 represents the cluster of propensity measures for these same individuals if they were to become new mode riders, as shown in Figure 2. If there is sufficient differentiation between the clusters, we may say that (for these attributes) there exists a different combination of attributes for automobile drivers than for this same group if they were to become new mode riders.

The distance between cluster means and the overlap of observations can be used to estimate whether automobile drivers are different from the new mode group in relation to the variables considered. Multiple discriminant analysis (11) can be used to test whether the differences found are statistically significant and to classify new observations by modal group. A discriminant function is the linear function of the set of variables characterizing the individuals in the sample that best discriminates between the clusters of observations representing the two groups. This function is such that it maximizes the ratio of the variance between the groups to the common variance within each group and consequently maximizes the "distance" between the means of the groups. In the general case, a discriminant function can be found for each group and takes the following form:

$$z = V_1X_1 + V_2X_2 + V_3X_3 \ldots + V_nX_n$$

in which

- X = variable measure,
- V = parameters that represent individual subjective weighting of the relative importance of each variable associated with it, and
- z = discriminant score, or value of discriminant function for the individual under consideration.

The vector of parameter values V of the discriminant function is analogous to the disutility weighting V for the individual from Eq. 3 and suggests the connection between disutility functions and discriminant functions. The analysis therefore gives a boundary condition that separates the modal groups on the basis of their average disutility, as measured by the parameter values and variables of the discriminant function.

When a group discriminant function is valued, it can be used to predict the propensity to shift modes. That is, the z value of any individual can be found and his group identified. Because the z value is a function of systems attributes and individual value orientations (which here are assumed to be stable, i.e., as parameters), any change in the system attributes will change the z value. If any individual's z value changes enough, it will transfer him from the region of mode 1 to the region of mode 3. At some extreme change in system attributes, all z values change sufficiently such that all members of the region of mode 1 are transferred to the region of mode 3. For any given policy change, the probability of an individual remaining an automobile driver or shifting to a new mode can be determined. Conversely, the probability of an individual shifting to a new mode can be stated as follows:

$$P(X) = e^z/(1 + e^z) \tag{4}$$

in which z is the discriminant function value (or discriminant score) for each individual as an automobile driver and in his potential group as a new mode user. The discriminant rule will assign him to the new mode if his z value is closer to the mean of the new mode group than to the mean of the automobile group; otherwise, the rule will leave him a member of the automobile group.

The method presumes some restrictive preconditions. Assumptions are (a) that every individual is aware of the potential alternatives, (b) that his preferences are rational in terms of the utility postulate of maximizing satisfactions, (c) that his behavior and stated preferences are coincident, and (d), which is related to c, that his perception of a preferred system is independent of the existing level of service.

Assumptions a and b present no particular problem because they are intrinsic assumptions of any analysis using utility theory. Assumption c is important to the practical application of the model as a device for making transportation decisions and therefore deserves some discussion. The congruence of stated preferences and behavior is tied to the relation between an individual's value system, as manifested in specific attitudes, and his behavioral response. Early behaviorists, who believed in the mechanistic behaviorist system of stimulus-response and resulting habit patterns, felt that attitudes were redundant in explaining social phenomena. Later, however, it was recognized by social behaviorists that the concept of attitude was needed to give reality to the idea of the mechanistic model of man. This concept was first introduced into the behavioristic system as a predisposition to respond and later in terms of the subjective meaning the attitude had for the individual (12). The current consensus is that attitudes and behavior are interrelated although the relation may go from a very weak connection to a very strong one. In the present case, it is postulated that individuals can articulate their evaluation of the transportation systems' attributes in terms of preferences and that, if these attributes are included in a new arrangement, there will be a tendency to react accordingly.

Assumption d presupposes that individual travelers can perceive a transportation system independently of the existing level of service. The validity of this assumption is examined later.

SHIFT PROPENSITY OF A SAMPLE OF COMMUTERS

The model was empirically tested by studying a sample of commuters in one radial travel corridor in Vancouver, Canada. The corridor tested served the "north shore" communities in metropolitan Vancouver and consisted of traffic crossing a high suspension bridge to the central business district (CBD). The catchment area consists of three municipalities with a combined population of about 107,000. It is separated from the CBD of Vancouver by Burrard Inlet and connected to it by the Lion's Gate Bridge. The data set was a sample of automobile drivers who crossed the bridge between 7 a.m. and 9 a.m. on a weekday in March 1967. The original survey was a "handout-mailback" modified origin-destination study conducted by a transportation consultant for the British Columbia Highway Department. At the time of the survey, the bridge carried about 6,500 automobiles in the 2 hours as well as 52 buses with about 2,500 passengers.

The present investigation used the data to study the potential impact on modal shift of (a) a hypothetical park-and-ride system and (b) changes in the use of existing bus transit if parking costs in the CBD were increased.

The performance dimensions used to estimate modal shift were those that defined the relative values of a preferred level of service in the hypothetical system and the actual level of service by car. The explanatory variables were those that defined the preferred level of service if a shift was to occur and those that defined the actual level of service experienced at the time of the trip. On the original questionnaires, each automobile driver was asked to indicate on a categorized scale the minimum quality of service desired for him to use a park-and-ride system and the maximum charge he would accept for parking before he would use bus transit. The preferred situation is measured by his stated preferences, which is used as the explanatory variable for the individual as a hypothetical transit rider. The actual measure is the explanatory variable for the individual as an automobile driver. The performance variables used in the model are the relative value of these characteristics. A description of these variables is as follows:

1. Relative overall travel time: The preferred relative door-to-door journey time by a park-and-ride system in 5-min increments as compared with that by automobile

Figure 1. Disutility of combinations of time and cost of two modes.

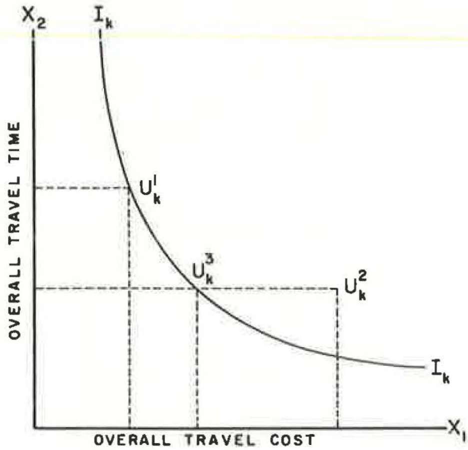

Figure 2. Disutility values illustrating two hypothetical modes.

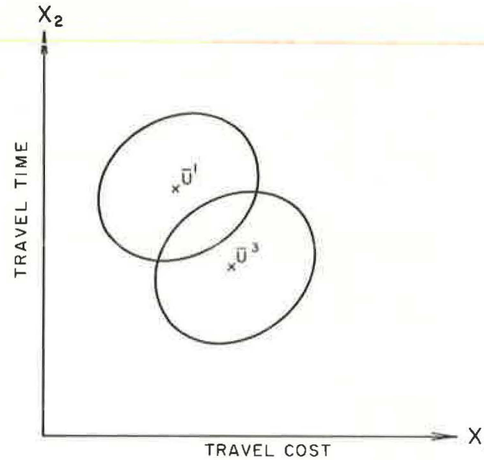

Table 1. Means and standard deviations for automobile and shift groups.

	Automobile Group		Shift Group		Average	
Variable	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
X_1	30.849	8.381	25.806	8.799	28.328	8.971
X_2	0.549	0.420	0.533	0.328	0.541	0.377
X_3	0.669	1.554	2.022	0.953	1.345	1.455
X_4	17.409	4.870	4.503	2.192	10.956	7.478
X_5	0.549	0.420	1.011	0.532	0.780	0.532

Note: X_1 = relative overall travel time, X_2 = relative out-of-pocket expenses, X_3 = relative residential travel time, X_4 = relative frequency of service, and X_5 = relative parking charge.

Table 2. Modal shift propensity for automobile and shift groups.

Variable	F-Ratio	F_p
X_1	80.09	<0.001
X_2	0.47	NS
X_3	256.03	<0.001
X_4	2,715.61	<0.001
X_5	215.20	0.001

Note: The variables are identified in Table 1.

Table 3. Correlation matrices for automobile and shift groups on system variables.

For Automobile Group	X_1	X_2	X_3	X_4	For Shift Group
X_1	1.00	0.12	0.11	0.15	X_1
X_2	0.09	1.00	0.12	0.15	X_2
X_3	-0.01	0.05	1.00	0.17	X_3
X_4	0.32	-0.05	-0.05	1.00	X_4

Note: The variables are identified in Table 1.

Table 4. Canonical tests of independence of preferred attributes with actual ones.

	Variable								
Variable	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	1.00								
X_2	-0.09	1.00							
X_3	-0.01	0.05	1.00						
X_4	0.32	-0.05	-0.05	1.00					
X_5	0.65	0.10	-0.08	0.27	1.00				
X_6	0.04	0.19	-0.06	0.04	0.12	1.00			
X_7	-0.02	-0.02	0.10	-0.07	0.11	0.12	1.00		
X_8	0.03	0.03	0.07	-0.00	0.15	0.15	0.17	1.00	
X_9	0.09	0.60	0.02	0.01	0.13	0.17	-0.08	-0.00	1.00

Table 5. Significance of canonical roots.

Root	Canonical Correlation (R_c)	χ^2	Discriminant Function Value	χ^2_p
1	0.678	493.5	20	0.001
2	0.595	202.0	12	0.001
3	0.155	11.7	6	0.05

was indicated by the respondent. This value was then converted to preferred absolute travel time and compared to the actual travel time by automobile. This process was carried out so that both differences and ratios could be used as relative disutility measures.

2. Relative out-of-pocket expenses: This variable is the maximum two-way combined bus fare and parking charge that the respondent would insist on before shifting as compared with the actual parking charge levied.

3. Relative residential travel time: This value is the walking duration from the parking location to the transit vehicle preferred in a park-and-ride system as compared with the actual walking distance from residence to automobile at the trip origin.

4. Relative frequency of service: This parameter is the preferred frequency of transit vehicles leaving the park-and-ride terminal in minutes as compared with the actual frequency of bus service in the zone of origin of the automobile driver.

5. Relative parking charge: This measure is the parking rate at which the respondent said he would switch to bus service if the parking rates were substantially increased in downtown Vancouver as compared with actual parking charge experienced at the time of the journey.

If the preferred service was provided, each driver willing to shift modes could, under the preferred conditions, be considered a user of the multimodal system. The automobile-driving population actually tested and the hypothetical users of the new system then define two groups in two regions of the test space. These would (in the statistical sense) be matched pairs with each member of each pair (i.e., group) being located at two points on an indifference surface, for example, at points U_k^1 and U_k^3 in Figure 1 for the case of two attributes. The problem is to find the discriminant function that maximally separates the two groups and the attributes that contribute to the separation. The significant discriminant function variates indicate the policy changes that would encourage drivers to change modes. The probable number of persons that would be classified as a park-and-ride system user or a bus transit user at any level of change in the system can be determined.

Because some people would shift only under the most extreme conditions, which may not have been covered in the questionnaire, a follow-up question was asked to determine if the respondent would definitely shift if the quality of service he specified was actually provided. Those who answered no to this question were eliminated from the sample, leaving a total of 465 respondents who said they would in fact shift if the service they desired was provided. Discriminant analysis was then used to determine (a) if actual individual behavior patterns of the original anchor group (i.e., actual automobile drivers) were significantly different from the preference patterns of the shift group (i.e., hypothetical park-and-ride or bus transit users' patterns based on the combination of attributes that they said would cause them to shift) and (b) what attributes serve to define the separation between automobile drivers that shift to a new mode and those that remain automobile drivers.

Two series of tests were carried out. The hypothesis of discrimination, using five instrument variables, was tested by using the program DISCRIM as documented in Cooley and Lohnes (13) and modified by the author for tape reading options. A second series of runs was made to test the effects of deleting some of the variables by a stepwise discriminant program using University of California, Los Angeles, program BMD07M (14). Posterior classification checks were also made by using the latter program.

The central tendencies of the observations of the two groups, as given in Table 1, give a general indication of the preference pattern of the automobile driving population with regard to shifting travel modes. If the distribution of both groups is assumed to be normal, the data in the table describe those measures needed to bring about a shift of one-half the automobile group. The other half would be those who required changes which locate them below the mean. This shift would occur with a decrease in mean travel time of about 5 min. Total out-of-pocket expenses would have to decrease, but not substantially. The overall walking time from the parking lot of a park-and-ride station to the bus compared with the existing time at the residential end of the journey would have to be about 2 min. This implies that drivers would tolerate this amount of walking at the residential end of the trip if other desirable characteristics are provided. One characteristic that shows up very dramatically is a large increase in the frequency of public transit vehicles needed within the park-and-ride system compared with the existing frequency of buses. The average driver who is a potential shift patron would require about 4.5 min of headway between buses as compared with the more than 17 min he has at present.

The parking charge needed, by itself, to effect the 50 percent shift to bus transit would increase from an average of about \$0.55 to about \$1.00 per day.

Some caution is necessary in the interpretation of these data. First, the large standard deviations for the out-of-pocket cost factor results from a few extreme observations of those who pay a very high parking cost at present and those who demand a very low total expense for the shift condition. Many respondents indicated that they desired a system with no out-of-pocket expenses. Second, the spread between the existing frequency and the one preferred may be biased because of the way they were measured. The existing frequency is a rush-period average for the zone of origin for each driver and may not represent the combination of extremely high or extremely low existing frequencies with extremely low or extremely high preferred frequencies on an individual basis. If precise frequencies were used for the hour of departure, the spread in means would decrease, and the effect of this factor would be expected to moderate somewhat.

The univariate F-ratios given in Table 2 give the relative importance of each variable when considered alone. F-probability tests show that all variables, except changes in parking expenses, are significant. For the park-and-ride system, the frequency of buses leaving the terminal shows the greatest contribution to the separation of modal groups. Walking distance from parking location to terminal loading point and overall travel time are also important variables when taken by themselves. The effect of parking charge increases on the shift to the bus mode is also shown to be significant. A statistic, Mahalanobis D^2, gives the standardized measure of the "distance" between the modal groups and is the difference in mean values on the discriminant function. D^2 for the separation of car mode and park-and-ride mode is 147.45 and between the automobile mode and the bus mode is 0.213. The more familiar R^2, which shows the effectiveness of discrimination by the ratio of variance due to regression of the differences between groups to total variance (or proportion of variance accounted for in the discrimination), can be calculated from D^2. The R^2 for park-and-ride propensity is 0.762 and that for bus transit is 0.175. Both R^2's are significant at the 0.001 level. However, the relatively small amount of variance extracted by parking charge changes on bus transit (17.5 percent) indicates that other variables would also be operative (and may be more important than parking costs) if they were included.

The relative contribution of each of the variables can be estimated by using a scaled vector of weights on the discriminant function. These are variable weightings, or coefficients, that are scaled by dividing through by the standard deviation of the variable in question. The vector of weights for each of the instrument variables tested is as follows:

Variable	Scaled Vector
X_1	-17.85
X_2	0.43
X_3	-11.48
X_4	108.13
X_5	14.61

These values show that bus frequency dominates the preferred attributes in a park-and-ride system. This reflects the differences found between the frequency preferred for each and that averaged by zone and then averaged over the rush period. The travel-time dimension, isolated by the analysis, distinguishes between existing and preferred services with frequency and residential travel time contributing substantially to the desire for a shorter duration trip. This test shows a relative insensitivity to the combined fare and parking cost variable.

The preceding analysis considers the contribution of each variable to the separation of the modal groups when taken as a system of variables. However, one of the variables tested is not significant (combined out-of-pocket expenses), and some intercorrelation exists between overall travel time and bus frequency as given in Table 3. Also, it is convenient for classification purposes to go to the general case and produce discriminant functions for each group. A stepwise discriminant analysis was therefore carried out in which variables were entered into the function according to three criteria: highest F-ratio value, highest multiple correlation, and greatest decrease in ratio of within-group to total variances. This program values the group functions for each individual and determines the posterior probability of each individual belonging to each group. The individual is assigned to the group for which he has the greatest posterior probability, that is, the largest P(X) value as calculated by using Eq. 4.

The discriminant functions as determined by the stepwise procedure of the anchor group for the park-and-ride system and the bus transit system respectively are as follows:

$$z_{a_{pr}} = -10.761 + 0.401X_2 + 1.221X_4$$

$$z_{a_{bt}} = -0.657 + 2.390X_5$$

Those for the shift group are respectively

$$z_{s_{pr}} = -1.940 + 1.216X_2 + 0.316X_4$$

$$z_{s_{bt}} = -2.222 + 4.397X_5$$

If we use an acceptance-rejection criterion of $F_p \leq 0.05$, out-of-pocket expenses and overall travel time drop out of the function, and the discriminant scores are calculated on the basis of residential travel time and frequency. This increases the F-ratio from F = 744.90 to F = 1,484.74 for the park-and-ride scheme. The R^2 of 0.760 for this scheme indicates good discrimination on only these two variables. The posterior classification by means of the discriminant functions results in less than 1 percent misclassification. Using only parking charge as a variable in the model produces only moderately successful results with almost 33 percent misses. This may be partially due to a relatively crude breakdown in the parking charge categories used in the survey, which were $10 per month intervals, with 60.5 percent of all responses in two categories, $0 to $10 and $10 to $20 per month, and 30.5 percent with free parking.

VALIDITY OF PREFERENCE MODEL

The modal shift described here is based on an analysis of what people say they would do when given a hypothetical situation. To improve study validity, we analyzed only those respondents who stated a second time that they would shift if their preferences were met. A question, however, still remains as to whether the respondents would in fact shift if their desires were met. Some attempt was made to further understand the preference structure of the sample to estimate the validity of stated preferences as a tool to analyze modal shift.

It was reasoned that, if an individual's preferences were independent of the level of existing service, it was likely that he perceived the hypothetical service attributes independently of his currently available service levels, and therefore propensity to shift was higher than if preferences were constrained by actual service conditions. Consequently, a correlation test of the independence of preferences from existing service levels was carried out by using canonical analysis. Canonical correlation analysis (15) is a statistical technique used to analyze the relations between two sets of variates when the sets are in some sense maximally correlated. As such, it is a generalized extension of multiple linear regression analysis but with multiple dependent as well as multiple independent variables making up the two sets of variables. In the case at hand, the technique helps us to understand how the set of perceived existing service attributes is related to the preferred set of attributes.

Table 4 gives the correlation coefficients for the four variables that represent existing attributes and the five variables that represent preferred attributes. (Preferred parking charge X_9 is compared with actual parking charge X_2 to account for the extra variable in the second set.) Some correlation exists between preferred travel time X_5 and actual travel time X_1 and between parking charge X_2 and preferred parking charge X_9.

The canonical correlation between the sets is significant (Table 5). Two roots with $R_c = 0.68$ and $R_c = 0.60$ are both significant at $p < 0.001$. The inference is that the two sets of variates can be combined in such a way as to produce correlation between what an individual prefers in the way of transportation service and the existing alternatives available.

The coefficients of the two sets for the first canonical variate are $X_1 = 0.881$, $X_2 = 0.280$, $X_3 = -0.135$, $X_4 = 0.121$, $X_5 = 0.952$, $X_6 = 0.025$, $X_7 = -0.138$, $X_8 = -0.089$, and $X_9 = 0.229$. These indicate that the factor contributing most to the intercorrelation is the relation between actual travel time and that which is preferred. The second canonical variate has the following coefficients: $X_1 = -0.355$, $X_2 = 0.967$, $X_3 = 0.038$, $X_4 = 0.008$, $X_5 = -0.381$, $X_6 = 0.140$, $X_7 = 0.087$, $X_8 = 0.052$, and $X_9 = 0.951$. This canonical variate brings out the remaining intercorrelations: that between actual parking cost and that preferred. The results indicate that, as far as travel time and parking cost factors are concerned, automobile drivers do not think that radical changes would be part of the hypothetical system. However, indications are that other attributes such as transit fares, residential travel time, and service frequency can be changed in a way very much different from that which is currently experienced.

SUMMARY OF FINDINGS

The results of the analysis support the concern of transportation planners with travel time. If a park-and-ride system could be developed that would reduce the overall travel time by about 5 min in a 30-min average trip, such a system would have a significant effect on the number of persons who would shift to the system. However, it is evident that the decrease in system overall travel time must come about by low levels of walk and wait time in the systems. Transit frequency within the overall system was shown to be the most important factor in a consideration of this type of system. But the frequencies demanded for a substantial shift are not unrealistic, with a frequency of 4.5 min achieving substantial success. Given a sufficient capacity and an efficiently designed feeder system (roads, parking, and feeder buses) such a system appears feasible.

Although residential walk times need to be minimized, the tests show that drivers will tolerate some walking in the system at the origin end of the trip. The mean walking distances preferred for a shift of just over 2 min is well within the usual walking distances most motorists face in other circumstances. For large cities, this may be up to 5 min at the destination end and somewhat less than 10 min at the origin end although little is known about this aspect of a motorist's walking tolerance. It is highly likely that if these were put together, however, the total of 15 min would discourage a modal shift (although in Vancouver almost 32 percent of those going to the CBD by automobile walk 10 or more min at the trip destination). Because substantial numbers of automobile drivers walk more than 5 min at trip destination and because park-and-ride as well as bus transit passengers would in general be deposited closer to destination, it seems likely that a 2-min walking distance at the parking-transit interface would cause no problem in encouraging the use of the system.

The insensitivity of out-of-pocket costs in the manner of combined bus fare and parking cost is difficult to interpret. Most studies have shown that transit fare decreases have little effect on diverting automobile drivers. On the other hand, parking cost is usually found to be a sensitive factor. One explanation is that the respondent perceives this combined expense as an over-the-road cost (which is usually not a strong incentive to shift) as he would vehicle operating cost or transit fare. It seems highly likely from the evidence available that vehicle operating costs are perceived differently than are parking costs in the "decision calculus" of automobile users. Transit usage is not directly related to transit fares because of the large number of transit captives who have no choice but to pay the fare and because automobile drivers put costs low on their list of priorities when considering transit. The psychological perception of a package cost, including fringe parking charge and transit fare, may be different from either a vehicle operating cost or a parking fee at the destination of a single automobile mode journey, and therefore automobile drivers are insensitive to a combined fare, particularly if the fare is collected at the line-haul terminal. On the other hand, a more rigorous breakdown of this cost in the survey stage may show different results.

As expected, parking charges levied in the CBD may have substantial effects on changing the modal split in favor of bus transit. Whether the charge is levied as a fee increase or as a tax would not affect the results because the important aspect of the factor is that it is not a hidden cost, such as vehicle operating costs. This appears to be a fruitful area in which to pursue ways of rationalizing modal balance.

CONCLUSIONS AND IMPLICATIONS

The use of stated preferences may be an effective means of determining the propensity of automobile drivers to shift to a radical new transportation system. Use of this technique on a somewhat conventional multimodal park-and-ride system gives expected results. Use of subjective preferences for a completely radical system depends on the link between preference patterns and subsequent behavior patterns. There appears to be two ways of allowing for this: (a) improvement of the survey instrument (e.g., the questionnaire) so as to be able to make inferences about preference-behavior linkages and (b) field-testing by structuring the model so that its inputs reflect incremental or largely noncapital changes to the system.

Some validation of the survey used here was undertaken, which provided inferential conclusions about whether respondents could perceive radical changes in the system and could differentiate between existing service and new levels of service. This was used to conclude that citizens viewed dramatic changes in extra-vehicular time to be necessary to encourage diversion to the park-and-ride system. This close link between the value given here to excess time and what we know to be the case with similar analyses of work-trip behavior patterns indicates that, in the case of travel time, stated preferences and behavior may be congruent. This study considered only selected variables (those available in the original study), and it is necessary to examine a much broader set of service variables (such as comfort for example) before definite conclusions can be made. The main emphasis on research in this area is to develop a much better survey instrument than the traditional origin-destination survey, one that allows, as a minimum, tests for reliability and validity of results.

The advantage of structuring a model in terms of the inputs investigated here (such as parking charges, bus frequencies, and walking times) is the possibility of including these in policies that can be implemented with relatively little capital investment. The methodology can be used to study and monitor the effects of these adjustments on the system. If the effects are not in the direction of preset community objectives, the model can be adjusted and new tests made. The factors found here to be subjectively important are in effect the antecedents of a control mechanism that is both goal-oriented and incremental, incorporating both system planning and decision-making in the long-term context and flexible control of the system to meet short-term objectives. However, such a scheme depends on an integrated concept of streets, parking, and transit and an institutional framework that is able to coordinate the planning of street elements, parking supply (both fringe and downtown lots), transit facilities, and fare and parking charge structures. If the institutional framework can be effected, the propensity model appears to be a useful tool to study modal diversion.

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SPECIFICATION AND EVALUATION OF ALTERNATIVE FEEDER AND LOCAL TRANSIT SYSTEMS IN A SUBURBAN AREA

James W. Schmidt, De Leuw, Cather and Company; and
Robert K. Arnold and Stephen Levy, Institute of Regional and Urban Studies

This paper is based on research conducted in a suburban county in the San Francisco Bay area on the specification and evaluation of alternative transportation systems to serve as a feeder to the new San Francisco Bay Area Rapid Transit system and as local transit. Forty-five percent of the employed residents commute to jobs in central cities outside the study area and more than two-thirds of the area households own two or more private automobiles. Major conclusions are that conventional bus systems will not substitute for private automobile use by the general public and are not economically justified either as a rapid transit feeder system alone or as a combined feeder-local transit system. Costs greatly exceed combined user and community benefits. New forms of public transportation systems are required. Small, publicly owned, electrically powered automobiles appear feasible and economically justified. The conclusions of the study may be applicable to the broader problem of collection-distribution links to corridor public transportation systems and local public transit systems throughout metropolitan regions of the United States and suggest the possibility of major substitution for second and third private automobiles by publicly owned automobile systems. The method of approach used in the study demonstrates the critical significance of feedback between specifications and benefit-cost evaluation of alternative systems. Use of an innovative "successive approximation approach" identifies key variables at the earliest time in research.

• THE objective of the Contra Costa Transportation Needs Study was to analyze alternative transportation systems to serve as a feeder or collection link to the San Francisco Bay Area Rapid Transit (BART) corridor system and as a transit system to meet local travel demands for local trips. The context in which the analysis was conducted, the method of approach, and the major findings and conclusions should have relevance for public transportation systems in many metropolitan regions of the United States.

The BART corridor system is scheduled to begin operation in 1972. Service from five stations located in the central part of the county will be provided initially to Oakland, the second central city of the San Francisco metropolitan region. By late 1972 or early 1973, BART transbay service will be extended to San Francisco.

The central area of Contra Costa County (Fig. 1) is made up of approximately 15 communities that together have experienced an increase of more than 50 percent in total population between 1960 and 1970 and are expected to increase in population by another 50 percent by 1980. The residents of the study area have relatively high incomes—the median values of owner-occupied dwellings as reported in the 1970 Census of Housing are significantly above the average for the state for most of the communities located in the study area. Private automobile ownership data are not available yet from the 1970 Census of Population, but extrapolations from data for the period 1960 to 1965 indicate that about two-thirds of all households in the central area of the county currently have

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two or more private automobiles. About 45 percent of all employed residents commute by automobiles to jobs located outside the area, principally in San Francisco and Alameda counties. Although the number of jobs within the study area is projected to increase by nearly 100,000, the number of intercounty commuters, particularly to San Francisco and Oakland, is projected to increase from 71,000 in 1965 to 136,000 in 1980.

The intercounty commuter from the central area of the county must currently travel through the Caldecutt Tunnel of the Berkeley hills, which represents a severe bottleneck. It is estimated that BART will save the average commuter (to San Francisco) between 10 and 35 minutes one way from the five stations located in the study area of the county.

METHOD OF APPROACH

A new planning approach of successive approximations and sensitivity analysis was used in the Contra Costa County Transportation Needs Study. This technique has been applied previously (1, 2). The approach has three concepts: simultaneous consideration of all study elements, development of final results by a series of approximations, and emphasis on evaluation of alternative systems.

Simultaneous Consideration of All Study Elements

The four major work elements of the new planning approach are preparation of inputs, specification of alternative systems, evaluation of alternative systems, and specification of implementation programs.

Work was begun on all tasks simultaneously at an early stage in the project to get preliminary results at the earliest possible date. Within the first month of the project, there were first-approximation results on system specification and evaluation. Simultaneous consideration of key study elements permitted the use of significant feedback from early results in later system design, evaluation, and implementation recommendations. Beginning the system evaluation process in the early stages of the project permitted early identification of critical issues. Because of the evaluation feedback, the research team was able constantly to focus the work on the most promising areas.

The concept of simultaneous analysis is shown in Figure 2 and compared with the usual transportation planning approach. First-approximation treatment of all study elements focused attention on key relations and provided a basis for allocating research effort to maximize project output. For example, preliminary evaluation results indicated that conventional bus service could not be justified for Contra Costa County even with substantial increases in projected ridership levels. Therefore, preliminary research being conducted simultaneously to calibrate a refined feeder bus patronage model was stopped and the work effort redirected to other critical items.

Development of Final Results by a Series of Approximations

Companion to the principle of simultaneity in the study approach is the method of working by successive approximations. A complete first-approximation analysis of conventional bus alternatives was completed and presented to the project board of control within 2 months after the study began. The sensitivity of initial conclusions to projections and assumptions used in the first-approximation analysis was reviewed in additional approximation phases. Primary work effort was diverted to identification and evaluation of other transportation systems as it became certain that the first-approximation conclusions would not change with reasonable variations in the input variables. Significant insights were gained by working with approximation results, and these insights guided subsequent approximations into more fruitful areas of research.

Emphasis on Evaluation of Alternative Systems

More emphasis was placed on the evaluation of alternative transportation systems during the course of this study than is usually done. A benefit-cost approach was chosen for evaluation on the premise that a comparison of total social benefits with total social costs is the most relevant evaluation measure for comparing alternative transportation systems. Alternative systems were evaluated by utilizing a broad definition of benefits and costs, which included identification of magnitude and incidence of community benefits and costs. Evaluation analysis was conducted simultaneously with other work elements from the beginning of the project. The early availability of evaluation results permitted the approximation analysis to be focused on the most meaningful areas, allowed for the refinement of the specification of alternative transportation systems, and contributed to the development of the major conclusions and recommendations of the study.

The benefit-cost evaluation methodology does not base its conclusions on the fiscal position of operators of transportation systems. The concept of benefits and cost is distinct from the relation between fare box revenues and operating costs. The relation between fare box revenues and operating costs does not give a basis for deciding whether to go ahead with a public transportation system or to choose among alternative systems. For example, on any particular trip, the fare represents the minimum number of benefits that the user thinks he will receive; otherwise he would not make the trip. On most trips, the actual benefits received by the user are in excess of the fares. Therefore, transit fares, in the first place, understate the number of real benefits that accrue to users of the transit system. In addition, transit fares do not reflect community benefits. For example, fares do not reflect any benefits that accrue to automobile users because of reduced congestion, or the savings from reduced parking requirements, or reduction in air and noise pollution. Therefore, the fact that fares collected by a transit system may fall short of operating costs is not sufficient reason to judge the public investment to be a poor one. However, if evaluation based on total social costs and benefits indicates that aggregate costs exceed aggregate benefits, then the public investment is not justified.

A second important aspect of the benefit-cost evaluation approach is the provision of information on the distribution of benefits and costs among various groups and jurisdictions affected by alternative transportation systems. This information aids decision-makers and the public both in choosing among alternative systems and in formulating ideas of how to finance the selected system.

ANALYSIS OF CONVENTIONAL BUS SYSTEMS

Four rounds of approximations were carried out in the complete analysis of conventional bus systems. A description of the principal features of each round will illustrate how the concepts previously discussed actually worked in the study.

First Round

The first round took about 4 weeks to complete and ended with a presentation of first-approximation results on all elements of the study—inputs, specification of alternatives, evaluation, and implementation. The principal tasks of the first round were development of estimates of BART patronage at each station in the study area, first specification of alternative feeder and local transit systems, and development of evaluation concepts and initial estimates of benefits and costs.

Estimates of BART patronage by station were developed from an analysis of the growth of employment and of commuting patterns among Contra Costa, Alameda, and San Francisco Counties. The first-approximation estimate was that there would be 12,000 daily one-way 7 a.m. to 9 a.m. work trips out of the study area on BART in 1980.

Four alternative levels of transit service (feeder and local) were specified and described in the first round. Initial estimates of system costs and of rider benefits from the feeder system were developed.

Second Round

The principal tasks of the second round were continued specification of alternative transit systems, development of patronage estimates for each alternative system, and evaluation of alternative systems.

Two significant feedbacks were discovered early in the second round, which allowed the research to be concentrated on more productive areas:

1. The initial estimates of patronage for the various systems showed that patronage did not expand as rapidly as did system costs. This fact combined with the early evaluation results meant that it was more likely that smaller systems would be economically justified as opposed to larger systems. Therefore, in the second round three additional minimum-sized systems were described and analyzed.

2. An initial benefit-cost evaluation of each system was completed in the second round. All systems had costs well in excess of benefits. On all systems, patronage would have had to double before benefits would have equaled costs.

The evaluation also brought out the distinction between the travel needs of the general public and the travel needs of limited-mobility groups (the elderly, young, and physically handicapped). On the basis of the results of the second round, a new component was added to the study. Research was begun to analyze alternative ways of providing public transportation service for limited-mobility groups. This analysis ended with the recommendations for the adoption of a dial-a-bus system.

<u>Third Round</u>

The principal task in the third round was a refinement of the benefit-cost evaluation of the most promising conventional transit system from the second round. All categories of benefits were reviewed to see whether the first evaluation had left out or undercounted significant benefits. The results of the third round were that the best conventional transit system had costs in excess of benefits.

Table 1 gives the results of the third round measurement of benefits. The feeder bus system benefits consist of savings in automobile ownership and operating costs to BART riders who use the feeder buses, savings due to the reduced number of parking spaces required at BART stations, reduction in cost of street improvements and congestion in the vicinity of BART stations because of diversion of BART riders to feeder buses from automobiles, and gains in income to commuters and reverse commuters which can legitimately be attributed to the feeder bus system. An aggregate feeder bus system benefit of $581,500 was estimated for this system. Total annual benefits for local-service work trip patrons was estimated at $232,500. The analysis of local-service work trips conformed to that used in the analysis of feeder bus benefits, except that, for each type of local-service work trip patron, benefits were estimated to be higher than those for the comparable feeder bus patron. Most of the upward adjustment of these benefits reflects the fact that local work trips would be of longer average length than the average trip from home to a BART station. Therefore, the average local work trip takes longer and accrues higher automobile operating costs than the typical trip to a BART station. In addition, the higher benefit levels estimated for elimination of an automobile reflected the belief that the car that would be eliminated would probably cost more than the car used solely for going to and from a BART station.

An estimate was made of benefits to users of the local transit service for nonwork trips (e.g., shopping, medical, and recreational). Those who make nonwork trips were considered as occasional users, and many of these users were judged to have no other transportation alternatives; hence, it was difficult to estimate the value of bus service for these users. Preliminary estimates were made to get an idea of the magnitude of benefits that would be needed to make any of the alternatives show more benefits than costs. Total annual nonwork user benefits were estimated at $360,000 based on a patronage projection of 360,000 annual round trips.

Estimates of community benefits from the local bus service component of the plan are given in Table 1. Benefits from reduced congestion due to the local bus service component would be very close to zero. Total ridership on the local service component represents only about 1 percent of the average daily total trips projected for the study area in 1980. With this low percentage of total trips diverted to buses (and considering the dispersed nature of origins and destinations in Contra Costa County), only a nominal reduction in congestion could be attributed to local bus service.

An estimate of $140,000 a year was made for the employment benefits that might arise from the introduction of local transit service. School bus operations of the various school districts were examined in detail to estimate the degree of school costs

Figure 1. Study area location.

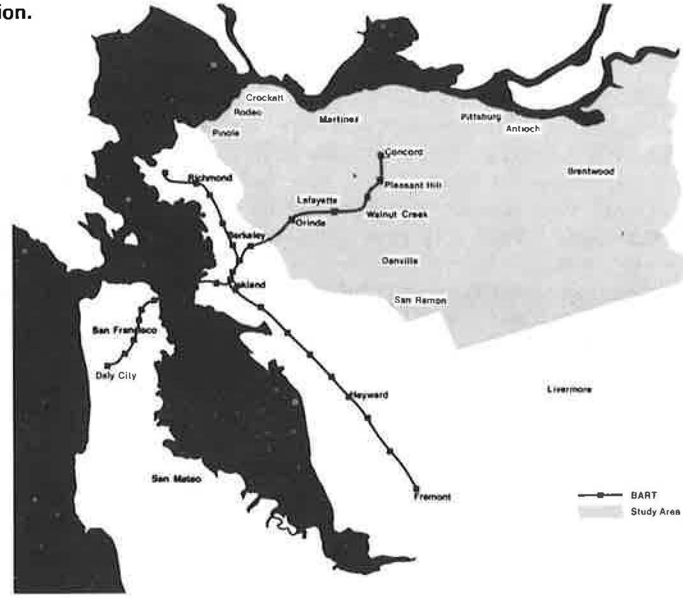

Figure 2. Alternative planning approaches.

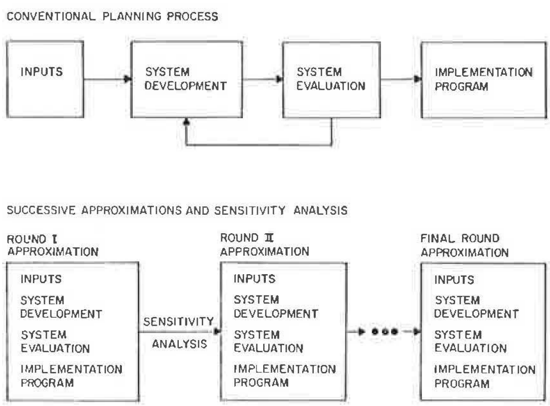

Table 1. Benefits of feeder and local transit systems.

	User Benefits		Community Benefits	
System	Source	Annual Benefit (dollars)	Source	Annual Benefit (dollars)
Feeder bus	Substitution for kiss-ride	230,000	Reduction in number of parking spaces	86,250
	Elimination of automobile	57,500	Reduction in congestion of stations and on roads to stations	165,000
	Elimination of automobile operating costs	11,500	Additional commuter income resulting from better job opportunities	50,000
	Loss from additional time in bus	(118,750)	Reverse commuter additional income from improved job	100,000
	Total benefit	180,250	Total benefit	401,250
Local transit	Elimination of automobile	139,500	Reduced parking requirements	30,000
	Elimination of automobile operating costs	93,000	Additional commuter income resulting from better job opportunities	140,000
	Elimination of ride to work	279,000	School transportation savings	80,000
	Loss from additional time in bus	(279,000)	Total benefit	250,000
	Occasional user	360,000		
	Total benefit	592,500		

Note: Total user benefits for both systems = $772,750; total community benefits for both systems = $651,250. Total annual benefits from all sources = $1,424,000; total cost = $2,000,000.

Table 2. PAS evaluation summary.

Type of Cost	Amount (millions of dollars)	Type of Benefit	Amount (millions of dollars)
Capital	19	Elimination of second automobile	27
Operating	10	Elimination of automobile operating expenses	10
Total	29	Parking spaces	2 to 4
		Total	39 to 41

Note: Net annual surplus of benefits = $10 to $12 million (1971 dollars). The following benefits were significant but not quantified: congestion savings, reduction in air pollution, and reduction in noise.

savings that might be realized by introducing a public transportation system in the study area. Even though school busing expenditures amount to more than $2 million, savings of only about $80,000 per year were estimated because of the public bus system. Higher operating costs for a public transit system; school transportation capacity, safety, routing, and related requirements; and coincidence of peak school and peak public transit passenger loads effectively preclude large-scale integration of school and public transportation services.

The final evaluation results show total annual benefits of $1.42 million and total annual costs of $2.00 million. It was concluded that, even with estimates of patronage and benefits that were judged high, total benefits would fall short of total costs for this bus plan and the other six alternative bus systems developed up to that point.

Fourth Round

Because of the broad ramifications and significance of the first- and second-approximation findings, it was decided to complete a final approximation of the planning and evaluation process, including refinements in specification of bus plans and the full evaluation. The objective was to check the conclusions of the earlier analyses from all points of view.

The final evaluation was conducted on two new bus plans—one a minimum plan with relatively low service standards typical of existing bus systems in suburban areas and the other a maximum plan with frequent peak-period feeder and local service. The bus plans were designed with two general criteria. The first general objective was to provide bus service within acceptable walking distance of as many households as possible so as to provide service to the greatest number of potential users in relation to the size of the system. The second general objective was to specifically orient routes to serve population subgroups with the greatest need for public transportation. These groups in central Contra Costa County consist of BART commuters in addition to so-called captive riders or persons with limited mobility who do not, or cannot, use an automobile.

Guided by the insights developed in the first three rounds, two new conventional bus systems were specified through refinements of the earlier systems. Routes, operating data, and service frequencies were refined on the basis of feedback from earlier rounds. The evaluation of these two additional alternatives did not change earlier conclusions. All nine of the conventional bus systems that were specified and evaluated had costs in excess of benefits.

The series of analyses conducted in these four rounds of bus system evaluation consistently demonstrate that conventional bus systems will fail in the suburban setting characteristic of Contra Costa County. The high proportion of families owning multiple cars, the high incomes, and the low land-use density all reduce the effectiveness of bus systems.

On the basis of these results, the study was continued along two lines. Analysis was undertaken to examine alternative ways of providing public transportation service for limited-mobility groups. In addition, effort was directed toward the question of alternative public transportation forms for the general public. This work led to analysis of the necessary attributes of a public transportation system to reduce automobile usage and to specification and evaluation of a public automobile system (PAS) for Contra Costa County to complement the BART corridor system.

MAJOR FINDINGS

The analyses of alternative feeder and local transit systems to complement the BART system in suburban Contra Costa County reveal several aspects of public transportation. Contra Costa is felt to be representative of many suburban areas in metropolitan regions of the nation. Therefore, the findings should have broad significance and application to many other urban areas.

General Public and Limited-Mobility Groups

In evaluating alternative feeder and local transit systems, it became apparent that two groups must be differentiated for rational analysis: persons and households who have access to automobiles as a transportation alternative and persons with limited mobility who do not own or cannot operate private automobiles. Clearly, in suburban areas, the general public falls in the first category; the elderly, poor, handicapped, young, and nondrivers make up the primary limited-mobility group. In Contra Costa County, 97 percent of all households own at least one automobile and more than two-thirds of the households own two or more private automobiles. Although these statistics are higher than for the nation as a whole, the pattern of higher levels of automobile ownership in suburban areas is common in most metropolitan suburbs. The population composition in central cities is decidedly different, with the limited-mobility group representing a much larger share of the total population.

The combination of greater mobility and transportation alternatives for the general public in suburban areas means also that public transportation, to be effective, must be capable of competing with the private automobile for trips made by the general public. Limited-mobility groups, by definition, have fewer transportation alternatives and are, therefore, more dependent on public transit. Moreover, their residence locations, trip behavior, and transportation needs are distinct from those of the general public and demand special analyses. Most elderly persons do not make work trips; young people are typically in school until midafternoon and the origin-destination focuses of their trips do not coincide with those of the general public.

Finally, public transportation will have to attract the general public in order to have any significant impact on highway traffic and congestion. Without shifts to public transit by the general public, transit in suburban areas will not reduce the dominance of the private automobile.

Conventional Bus Systems in Suburban Areas

Because of dispersed, low-density land-use patterns and multiplicity of origin-destination trip combinations, conventional bus systems in suburban settings will not be widely used. Feeder systems to rapid transit, schedule limitations in the choice of trip times, relatively long access times or distances, and waiting times for bus service will preclude effective reduction in the use of the private automobile. Private automobiles will be the dominant feeder made to the corridor public transit system.

In order for public transportation to be of value to residents of an area, the routes and service must be conveniently accessible. Few people are willing to travel farther than ¼ mile to reach a bus stop. Indeed, evidence from many communities shows that most bus patrons travel less than three blocks to reach the bus. Densities between 4,000 and 10,000 persons per square mile are common in suburban portions of even large metropolitan regions. At these densities, bus routes spaced at ½- to 1-mile intervals on major arterial streets are not within acceptable distances of many residences. The most extensive of nine different bus route plans evaluated in Contra Costa County would allow bus routes to reach (within ¼ mile) only half of the residences. Even in communities where more extensive route coverage was provided, only about three-quarters of the residences were within ¼ mile of the bus routes.

Other typical suburban development patterns present additional difficulty in rendering conventional transit service. Curvilinear and noncontinuous streets, cul-de-sacs, and hillside residential development preclude effective service by public transportation. Thus, even with an extensive system of local bus routes, a high share of the residents would be beyond acceptable distances from the bus routes.

Only a very small percentage of residents who could reach the bus system would use it. The performance and cost savings to the individual—even at a very modest fare of 25 cents—would not be sufficient to induce large numbers to switch from private automobiles. The largest bus system tested for central Contra Costa County would attract only 23 percent of 1980 peak-period BART commuters. Only about 1 percent of the 1980 local trips within the central county was projected to be made on the largest conventional bus systems. High car-ownership levels, dispersed pattern of origin and destination travel, and the inability to meet automobile competition in terms of accessibility, flexibility, cost, and time are the principal reasons that public transportation in suburban areas cannot capture a significant share of total travel.

Benefits to the community at large through a reduced requirement for parking space, less traffic disruption in neighborhoods, and reduced congestion on the street network could be compelling reasons to support implementation of public transportation service. However, for these benefits to be realized, there must be measurable substitution of travel from private automobiles to the bus system. The low patronage for a conventional bus system in central Contra Costa County precludes significant impact on parking, noise, traffic, congestion, and air pollution. With only 1 percent of all trips projected to use the bus system, it is clear that community benefits would be minor.

Nine conventional bus systems were delineated and evaluated. The lowest cost of installing and operating a conventional system was approximately $0.80 per passenger trip. The capital and operating costs for each of the nine conventional bus systems exceeded the combined user and community savings in each case.

The initial plan alternative considered the creation of a BART feeder bus system only. Capital and operating costs for a feeder bus system would exceed savings to the user and community by a factor of 4 or more. Revenue from feeder service, based on 25-cent fares, would cover only about 15 percent of the total annual cost of providing this service. Combining BART feeder bus service with local bus service within central Contra Costa County would improve operating performance but still require nearly 70 percent of total cost to be met from general community sources. The cost per passenger for rendering public transportation service would exceed automobile costs by a factor of 2. Savings to those who use the bus system and to the community (reduced parking, noise, congestion, and pollution) would be significantly less than the annual operating and capital debt retirement cost for any of the transit systems. On purely economic grounds, conventional bus systems must be regarded as a poor public investment in a suburban area because costs are well in excess of savings to the public. If public transportation is to be rendered on social criteria apart from economic considerations, it can be demonstrated that alternative forms of transportation are more cost-effective than conventional bus systems.

Feeder and Local Transit Systems Evaluation and Corridor Evaluation

Analysis of the transit collection-distribution problem as a distinct entity has been very limited. Most analyses have focused on corridor systems. Typically, feeder and local transit services have been evaluated in conjunction with the corridor elements without explicit independent consideration of the feeder-local transit component on its own merits. Consequently, the feeder system frequently has been rationalized on the merits of the corridor system. This treatment has clearly masked the real feeder issues and the proper evaluation basis, particularly with regard to suburban areas. The Contra Costa County feeder and local transit evaluations demonstrate that patronage on the corridor system does not depend significantly on the existence of a feeder system and that private automobiles will perform most of the feeder function (collection to and from places of residence) but not the distribution function at nonhome trip ends in suburban areas. If inroads are to be made on the use of private automobiles and the negative external impacts of private automobile-dominant transportation systems, new forms of public transportation are needed to complement corridor systems such as BART.

The Corridor-Public Automobile System Concept

Based on the findings and conclusions concerning conventional bus systems, the identification, specification, and evaluation of alternative forms of public transportation systems became necessary. The emphasis was placed on those systems that would compete with the use of the private automobile and would meet the demands of the general public residing in central Contra Costa County for trips to BART stations and for local destinations.

Major studies of new public transportation systems conducted under the auspices of the Urban Mass Transportation Administration were reviewed, and further research was conducted to determine costs, adaptability, and feasibility of several systems for consideration in the suburban area of Contra Costa County. The corridor-PAS concept was selected because its operational performance characteristics can compare favorably with the performance of the private automobile.

The corridor-PAS system has two components: frequent, high-performance public transportation service such as BART in major corridors of the metropolitan region and a publicly owned automobile system (PAS) consisting of a fleet of small, self-driven, electrically powered vehicles. Widely available in convenient stands throughout the urbanized area, the PAS fleet would provide collection and distribution service to the corridor systems and would accommodate short, local trips under 4 to 5 miles in length. The PAS would have five essential elements: public ownership; a large fleet of small, electrically powered vehicles; curbside stands and terminals widely distributed throughout the urban area where users would obtain or return a vehicle; a central computer information and control system to monitor vehicle and terminal use; and means for redistributing vehicles among the stands and terminal.

Public Ownership of PAS Vehicles

Public ownership of PAS vehicles would be necessary for three principal reasons:

1. Multiple use of PAS vehicles would be necessary to gain system economies. Therefore, the vehicles must be available for use by several travelers rather than sitting idle during the day; redistribution of vehicles to meet midday demand would be necessary.
2. A very large fleet would be required to achieve sufficient scale for the system to be widely used. The PAS vehicles would have to be available over a relatively large area and in sufficient locations and number to render confidence in the system and assurance of vehicle availability.
3. Perhaps most critical, the vehicles must be publicly owned in order to provide service from the corridor system to final destinations. The availability of PAS vehicles would allow individuals to use corridor systems and to get to many more locations than would be accessible without a PAS. In suburban areas, a system complementary to the corridor system is required to reach most destinations. The PAS would provide this critical link to the corridor system.

PAS Vehicles

Small, publicly owned, electrically-powered automobiles with room for two adults or one adult and two children would be used in the PAS. Later versions might have greater capacity. Vehicle prototypes have been developed for both electric and electric-hybrid PAS vehicles. PAS vehicles would be 9 ft in length or roughly about one-half the length of conventional automobiles. The vehicles would have interior space for both driver and passengers comparable to full-sized automobiles. Space for parcels would also be provided. A body shell of fiberglass or plastic cellular construction would be lightweight with high durability and attractive appearance. PAS vehicles would meet federal automotive safety standards and could operate on urban streets with mixed automobile traffic. Speed capability of the vehicles would be moderate (25 to 35 mph maximum) because operation would be intended for urban street conditions with restricted speed limits and short distance trips. PAS vehicles would not be allowed to use freeways or expressways. Moderate speed performance requirements are an important feature, considering the high-cost trade-offs between performance and capital and operating cost. Occupancy of the vehicle would be for short duration; therefore, interior appointments would not be elaborate. Controls and seating would be adjustable and suitable for a variety of different operators.

PAS Curb Stands and Terminals

The PAS vehicles would be available to users throughout the urban area at curb stands in neighborhoods and major terminals at key locations such as BART stations, shopping centers, and employment complexes. The curb stands would be constructed on public right-of-way, probably occupying the parking lane on residential streets. Curb stands typically would vary in size from 4 to 12 or more vehicles depending on development density and expected trip demand. At BART stations, space for several hundred PAS vehicles might be necessary to accommodate peak demands.

Central Control and Information Subsystem of PAS

A centralized control and information subsystem would be required to perform several functions within the PAS. On-line monitoring of the curb stands and terminals for fleet inventory control, communications with the system attendants for redistribution operations, and accreditation of users as well as off-line billing operations are functions of the control information subsystem.

Sensors would be needed at each stand and terminal to report the number of vehicles and to detect vehicle check-out and check-in operations. Use of the PAS would be restricted to accredited drivers who would be billed on a time and mileage basis. The central information system would verify user accreditation and record information needed for customer billing during check-in and check-out procedures.

Because the control system would be essential for operation of the entire PAS, provisions for handling and/or recovering from all types of system failures would be necessary. Complete backup control systems might be required to ensure uninterrupted system operation.

Redistribution of PAS Vehicles

A key requirement of the PAS would be the capability to efficiently redistribute vehicles. Demand patterns would result in surplus vehicle accumulation at BART stations and employment centers in the morning. In order to achieve multiple use, these vehicles would have to be redistributed to PAS stands and terminals in accordance with anticipated demand patterns. In the evening, vehicles would be assembled at BART stations and job locations to serve returning commuters and local employees. An efficient and economical method to balance the supply and demand for vehicles throughout the system must be devised.

Economic Evaluation of Corridor-PAS Concept

An example was developed to illustrate how a PAS of 30,000 vehicles might operate in the central area of Contra Costa County. The example provides a basis for preliminary estimates of patronage, operating and capital costs, and a first-approximation economic evaluation of the PAS.

Evidence from the example case in Contra Costa County suggests that there is a strong economic justification for the implementation at the regional level of a full system of public rapid transit in major corridors combined with a PAS for feeder and local trips. Two key hypotheses of the corridor-PAS evaluation were as follows:

1. Many of the households with two or more automobiles would find a corridor-PAS system a convenient substitute for the second car. The capital and operating costs of the corridor-PAS system would be more than offset by reductions in the cost of the private automobile and its infrastructure (streets, highways, etc.) to county residents.

2. Benefits and costs associated with the corridor-PAS would be widely distributed among all county households. It was concluded that the corridor-PAS could substitute for the second car of many households because its performance characteristics in terms of scheduling flexibility, routing flexibility, accessibility, convenience, privacy, journey speed, and cost would be directly competitive with the private automobile for the majority of trips made by suburban households. In addition, community benefits resulting from reduced parking requirements, reduced congestion, and reduced noise and air pollution would accrue to all households. Evaluation results are summarized in Table 2.

IMPLICATIONS OF RESEARCH FINDINGS

There are three public transportation problems in metropolitan areas where these findings may be applicable. The collection problem per se (i.e., linking origins with public transportation corridor systems) will become increasingly important with the continued expansion of urban corridor systems like BART. Further research can determine how broadly the conclusions of this study regarding the failure of conventional bus systems apply to other areas. Of prime interest is the relation of density of development to the benefit-cost evaluation of alternative systems.

Possibly a more significant implication of this research is the development of distribution systems to complement corridor systems at the destination end. Although people can drive from their homes to the rapid transit station (if buses are not justified), there is no such flexibility at the destination. Under what circumstances could a PAS function as a distribution system from the corridor? How much would the use and benefits of a corridor system expand if there were a good distribution system at the destination end? Now people can use corridor systems only if they are going to a restricted number of final destinations; otherwise, they cannot get to their final destination from the corridor system.

Beyond the context of corridor travel the implications of this research may be even larger. A concept like the PAS may open up the possibility of substitution for a substantial share of automobile travel by providing for local trips as well as links to the corridor. The PAS for local trips in combination with a public transportation corridor system for longer trips can do something that either alone cannot do. A corridor-PAS system can possibly serve the total travel needs of families, allowing them to get rid of at least second and third cars. What are the travel demands of families in terms of variety and length of trip? Under what circumstances could a PAS in conjunction with a public transportation corridor system satisfy the travel demands of a family sufficiently to allow them to get rid of a car? These are only some of the research questions that must be answered before the total implications and generality of the corridor-PAS concept become clear.

SUMMARY

Research on the corridor collection-distribution problem in a suburban setting has demonstrated serious question of the viability of conventional bus systems for either feeder or local transit functions. Although further evaluation is clearly needed to fully substantiate all elements of the PAS, the evidence developed in this project and earlier research work suggests that the concept should be pursued and that it merits far greater attention than it has been accorded to date.

The successive approximation approach and concept of evaluation as used in this study is a powerful analytic framework for transportation planners. By developing early evaluation feedback, the planner gains significant insight that can be used to improve the plan delineation process, and the project research effort can be sharply focused on those critical issues that affect final conclusions and recommendations.

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48-59

DESIGNING URBAN TRANSIT SYSTEMS: AN APPROACH TO THE ROUTE-TECHNOLOGY SELECTION PROBLEM

John C. Rea, Pennsylvania State University

The service specification model is a tool for generating and screening public transportation systems during the initial planning stages. It is based on the concept of a service specification or supply function that integrates hardware system attributes and operating policy. A service specification is an integrated set of statements that defines which hardware-headway combination is to be used for any level of flow across a link. Walk mode may be included in the specification. The model defines a transit system within a network which includes all potential and existing transit links. The current model assumes that transit demand is known. The mechanism of the model is an iterative assignment procedure that is similar to the capacity restraint model. The template network is started at the "best" hardware-headway service level. Link service levels are iteratively adjusted to correspond to link flow level as specified by the service specification. The iterative process ends when no further changes in link service level are required. Empirical tests show that the model is sensitive to the policy decisions and hardware mix incorporated in the service specification and to the size and orientation of the transit demand. The attainment of an equilibrium flow distribution appears to be influenced by the form of the service specification, the percentage of nonplanar links, and the presence of fixed transit-time links in the template network. The model appears to be a useful tool for generating alternative transport system configurations based on different technology mixes and operating policies in any transportation context for which a service specification can be formulated.

•CONCERN for the quality of urban life has, in recent years, resulted in a renewed interest in public transportation as a possible means of improving the environment of our cities. Although much attention has been directed toward innovative hardware systems, relatively little attention has been given to the development of models specifically oriented to public transportation planning.

The models currently used in the public transportation planning process are, on the whole, those developed for the planning of highway transportation. It is surprising that more models have not been developed to take advantage of the unique characteristics of public transportation systems. Two examples will serve to illustrate some basic differences between private and public transportation. The level of service provided by a public transportation system improves as demand increases because of lower headways and the viable use of higher performance hardware systems (assuming that an acceptable level of comfort is maintained and that the supply of public transit capacity is adequate). In contrast, the level of service offered to a highway user declines as demand increases because of vehicular congestion. The automobile is, at least in North America, the only practical private passenger transportation system; in the case of public transportation, a wide array of technologies and operating policies are possible.

Some models that incorporate the inherent characteristics of public transportation modes have of course been developed. Among them are, for instance, a minimum path

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algorithm for transit networks (1), Morlok's model for integrating intercity transportation networks and technologies (4), a large number of scheduling algorithms (5), and an array of modal split models (3). Perhaps the most important missing element in the public transportation modeling process is a model capable of designing transit networks that take into account the particular characteristics of the hardware systems to be used, the manner of their use, and the size and locational pattern of the demand to be served.

PURPOSE OF THE MODEL

The model presented here is an attempt to take advantage of the special characteristics of public transportation systems. It allows the planner to easily manipulate and explore the wealth of alternative hardware systems and operating methods. The model is a tool for generating and planning public transportation networks. In particular, the model is primarily intended to be an exploratory screening technique. It is used to quickly explore a wide range of public transportation alternatives based on different mixes of hardware systems and operating methods and to thereby identify systems worthy of further detailed study. The model translates a selection from the option set into an impact set as shown in Figure 1. Varying the attributes of the option set produces different impact sets, and alternatives may be evaluated in terms of the quality of the impact set.

The place of the model in the transportation planning process is shown in Figure 2. The service specification model is intended to be used as a screening model for selecting those alternatives worthy of more detailed study.

There are three basic inputs to the model. The first describes the potential transit network, the second describes the proposed hardware systems and operating methods, and the third describes the size and orientation of the transit demand. The relation between the model inputs and the option set is shown in Figure 3. The formulation of these inputs is now described and the model's philosophy developed in the process.

TEMPLATE NETWORK

The first input is a combination of link and node options. This network, termed a template network, is a synthesis of all possible and acceptable route alignments in the study area; i. e., it encompasses all of the potential links of the public transportation system. The concept of allowing the planner to select his system configuration only from among a predefined set of links is somewhat novel in transportation planning. Traditionally, the planner has been virtually unconstrained in laying out a system configuration, provided of course that the alignments were feasible and available.

A potential route is represented by a link in the template network; any restraint (with regard to the hardware system that may be used on the route) is affected by attaching a hardware usage constraint to the link. Nodes in the template network represent loading, unloading, and/or transfer points. The process of constructing the template network offers a framework for discussions with each community prior to, rather than after, the preparation of the transportation plan. A second feature of the template network is that it effectively deals with the usual combinatorial problem involved in generating and planning alternative system components and configurations. The problem becomes, in effect, one of link elimination rather than one of link addition. An example of a template network is shown in Figure 4. The problem is to define, within the template network, a subset of links that serve the imposed demand in a manner consistent with the proposed service specification. The latter input is now explained.

SERVICE SPECIFICATION

The second input describes the types and performance characteristics of the proposed hardware systems and defines how they are to be used. This input takes the form of an explicit statement that defines which hardware-service frequency combination is to be used for a given level of flow across a link. This statement is termed the service specification. Every service specification or supply function represents a particular selection from the option set. The supply function consists of different service levels.

Figure 1. Function of service specification model.

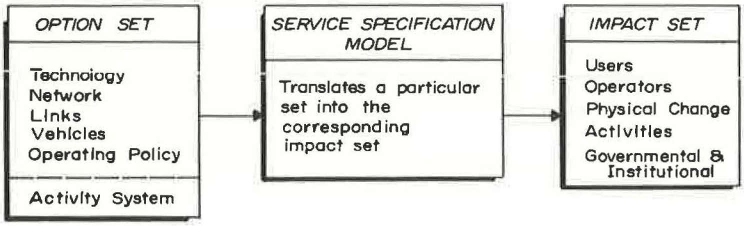


Figure 2. Relation of service specification model to transportation modeling process.

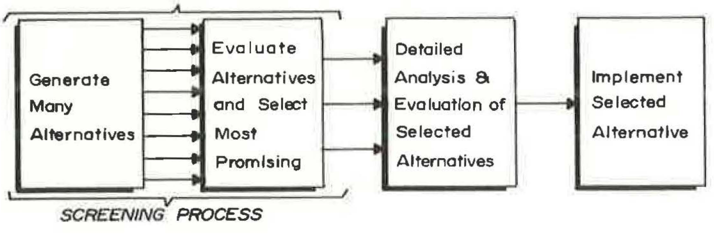


Figure 3. Relation between option set elements and model inputs.

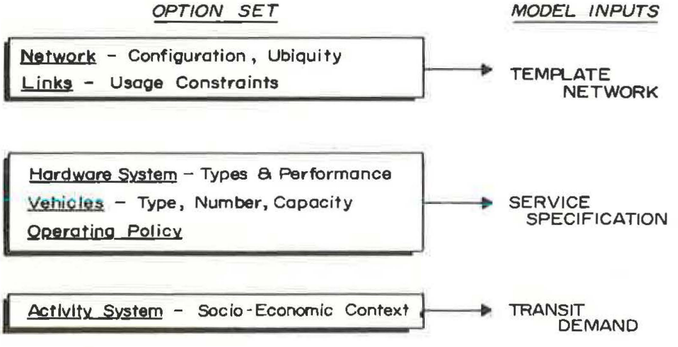


Figure 4. Example of template network.

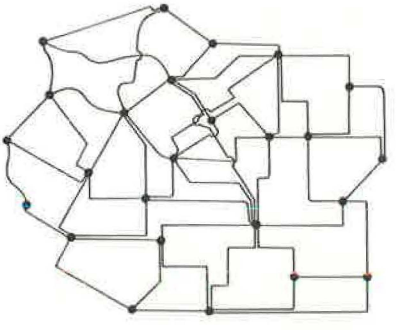
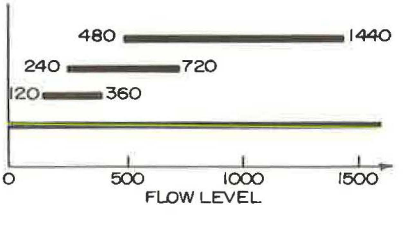


Table 1. Example of service specification.

Service Level	Type of Technology	Technology Conformation	Headway (sec)	Maximum Speed (ft/sec)	Acceleration (ft/sec^2)	Proposed Usage Range (persons/hour)
1	Rail	4 cars, 80 seats each	90	88	6	More than 6,400
2	Rail	2 cars, 80 seats each	90	88	6	3,201 to 6,400
3	Rail	2 cars, 80 seats each	180	88	6	1,441 to 3,200
4	Bus	60-seat bus	150	44	4	721 to 1,440
5	Bus	60-seat bus	300	44	4	361 to 720
6	Bus	60-seat bus	600	44	4	120 to 360
7	Walk	–	0	4	–	0 to 119

Figure 5. Service levels and corresponding flow ranges.

Technology	Heading (mins)
60 seat bus	2-1/2
60 seat bus	5
60 seat bus	10
Walk	(4 ft/sec)



Each service level corresponds to a specified range of flow levels and is defined by a technology type, a technology configuration, a service frequency, a maximum operating speed, and an acceleration (and deceleration) capability. Note that the walk mode can be encompassed by this framework. An example of a service specification is given in Table 1. This specification is obviously only one of many ways of supplying transportation service.

The basic rationale of a service specification or supply function is now described. As an example, consider the use of the service level offered by a 60-seat bus at a headway of 5 min. If all passengers are seated, the maximum capacity of this service level is 720 passengers per hour. This defines the capacity limit of the service level. One could theoretically offer this service level for all flows from 0 to 720 passengers per hour. In practice, a viable operation is achieved by establishing a lower limit. If the operating cost of the example service level is $12 per hour per mile and a fare of 5 cents per mile is charged, the break-even flow would be 240 passengers per hour. The range of flows for which this service level is viable and physically possible is thus from 240 to 720 passengers per hour.

This type of calculation can be performed for any technology-headway combination. An example for a 60-seat bus is shown in Figure 5.

Each technology-headway combination also implies a quality of service that, simplistically, can be taken as the overall travel speed, i. e.,

$$d/[t + (h/2) + s]$$

where

d = trip length,
t = time on vehicle in motion,
h = headway at boarding point, and
s = dwell time at intermediate stop.

More complicated formulations are possible, but this will suffice for the present purpose. By means of this interpretation of service quality (or any other), service levels can be ranked on a vertical scale as well as the horizontal flow scale. The data used in Figure 5 have been reinterpreted on this basis (for a 2,000-ft link) as shown in Figure 6. These concepts lead to the formulation of a service specification envelope for the 60-seat bus technology as shown in Figure 7. It is possible to formulate many different service specifications within this envelope to reflect different operating policies as exemplified in Figures 8a through 8d. The specification envelopes of different hardware systems can be superimposed to define an envelope for a mixed technology system as shown in Figure 9.

Note that the envelope is a guide rather than an absolute constraint in formulating specific service specifications. The viability boundary can be transgressed if one is willing to accept the economic consequences. The capacity boundary can be crossed if standees are acceptable. Each service specification will result in the definition of a different transit system and impact set.

The viability boundary of a service specification can be based on operating or total costs. Given the federal capital grants program and the communal benefits of a transit system, one could argue that the viability boundary should be based on operating costs. Economists would probably advise a total-cost criterion. Because the extent of the transit system is not known initially, there are some difficulties in basing the viability boundary on total costs unless one is willing to assume that the infrastructure cost per mile is constant. The use of a flat-fare rate instead of a per-mile rate also introduces some difficulties, but these can be overcome by assuming that a fare contributes to the support of each link in a utilized trip path on a pro rata distance basis. The income accruing to each service level can be obtained by summation. The initial arbitrary flat rate can then be adjusted as required to recover operating or total costs as the case may be. These, and other, aspects of the service specification obviously warrant more discussion than space allows here.

Figure 6. Service levels, flow ranges, and quality of service.

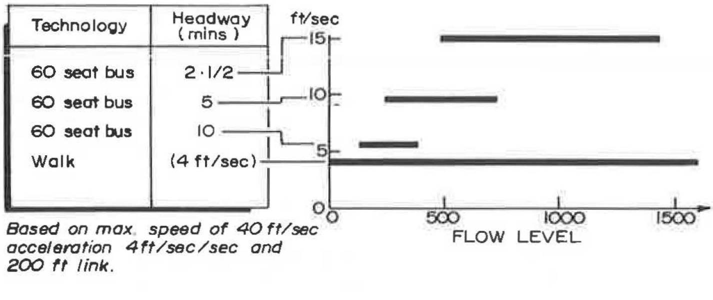


Figure 7. Development of service specification envelope.

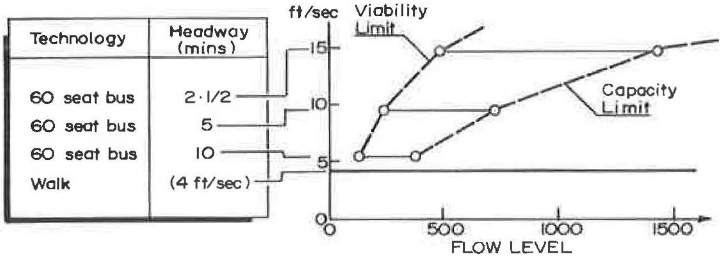


Figure 8. Hypothetical service specifications.

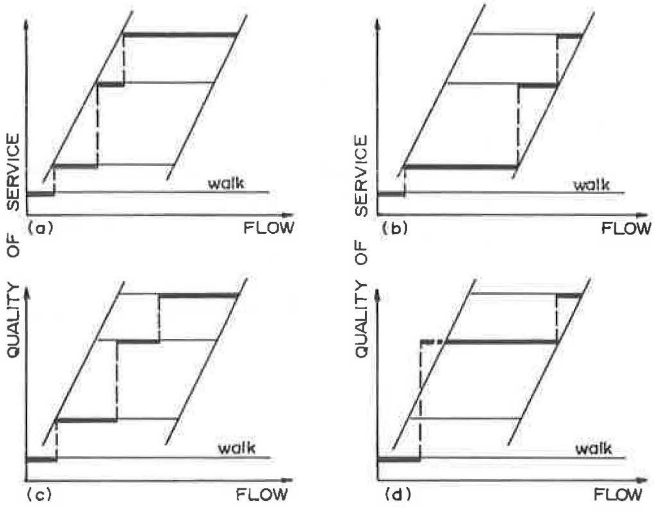
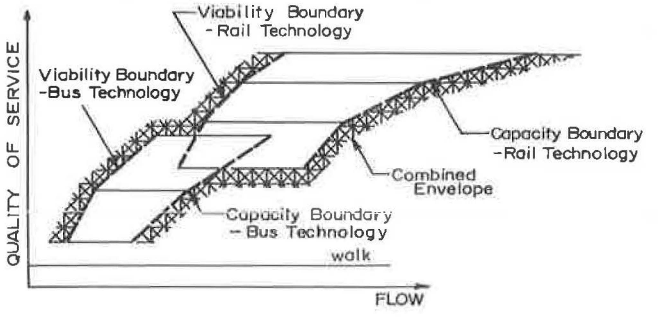


Figure 9. Specification envelope for mixed technologies.



TRANSIT DEMAND

The third input to the model describes the size and orientation of the demand that the system must accommodate and takes the form of a trip table showing morning peak-hour origin-destination (O-D) flows. The template network should preferably be formulated such that the origins and destinations are also network nodes. Although this is not a requirement, it does reduce the number of links and nodes involved in the analysis and reduces computer running time and costs. In addition, the use of a "spider" network is compatible with the use of the model for screening purposes.

The grain of the template network and the size of the demand-analysis zones should have some correlation. A coarse template network is suitable for identifying transportation corridors on a metropolitan scale, and the usual size of a demand-analysis zone would be appropriate in this case. A fine-grained template network with corresponding small-analysis zones would be appropriate for a microanalysis.

ALGORITHMIC PROCEDURE

The algorithmic procedure of the service specification model is essentially the same as that of the capacity restraint model. In the capacity restraint model, O-D flows tend to disperse across the network because, for highways, the quality of service on specific links declines as flow levels increase. Thus, a trip-maker may achieve a shorter trip time by traveling a longer distance to bypass areas of highway congestion. In the service specification model, O-D flows tend to concentrate in corridors of movement because the quality of service offered by a public transport system improves as flow levels increase. Thus, a trip-maker in this case may achieve a shorter trip time by traveling a longer distance in order to take advantage of the faster service provided on links with a high level of flow.

The effect of this concentration of flows is to leave some links with such low flows that they no longer warrant transit service (as determined by the service specification). Such links are assigned a service level equivalent to the walk mode and are in effect eliminated from the template network, thereby defining the transit system configuration. The transformation is shown in Figure 10. A more graphic way of interpreting the algorithmic process is to regard it as a battle in which links compete with each other and acquire as high a service quality as possible. As a result of the interlink competition, some links win and receive higher quality status sets and other links lose and become mere walk-mode links.

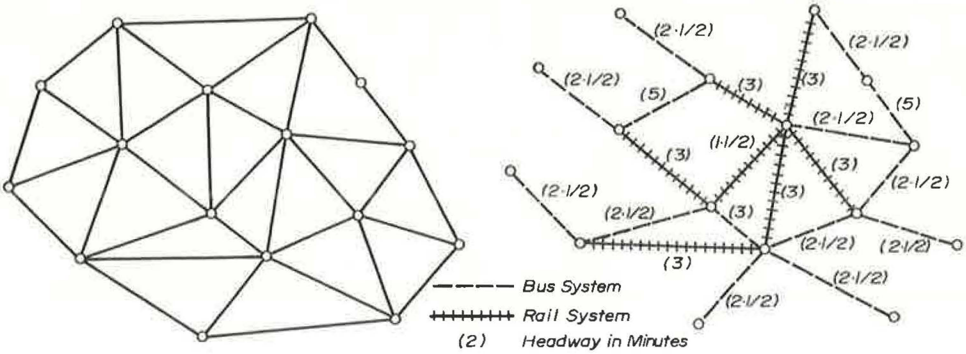
Link elimination, or, more positively, the definition of the transit system configuration, is achieved by establishing an equilibrium flow condition within the template network. The equilibrium flow condition is achieved by means of an iterative procedure, the steps of which are as follows:

1. Step 0: attribute to all links in the template network the highest service level ("initialization").
2. Step 1: determine minimum time paths through the template network between all origins and destinations.
3. Step 2: load each O-D demand onto links in the appropriate minimum paths.
4. Step 3: check each link's service level and loading for correspondence in the service specification.
5. Step 4: if correspondence is lacking, change the link service level to that warranted by its flow level in accordance with the service specification and go to step 1. If the service level and flow level of all links correspond, as defined by the service specification, stop.

A flow diagram of this algorithm is shown in Figure 11. The elements of the algorithm are now discussed.

The objective of the "initialization" process is to ensure that the template network is initially of uniform quality. Thus, no link has any initial advantage other than its inherent position and orientation characteristics. Given this condition, a link will attract flows to it only by virtue of its inherent attributes vis-à-vis the size and orientation of the O-D demand.

Figure 10. Definition of transit system within template network.



(a) Template Network

(b) Transit System Defined Within the Template

Figure 11. Algorithm flow chart.

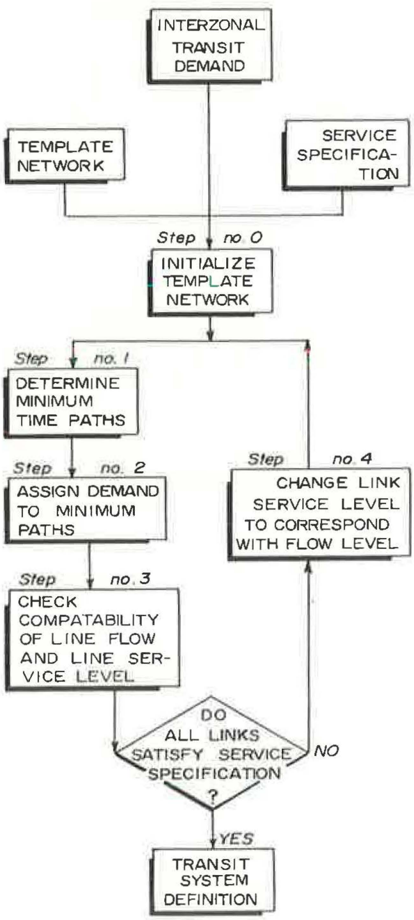
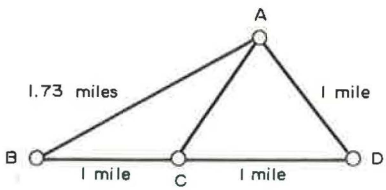


Figure 12. Input data and assumptions for example.



(a) Template Network

from \ to	B	C	D
A	200	400	100
B	0	400	400
C	500	0	300
D	400	600	0

(b) Trip Matrix (passengers/h

Service Level	Technology	Headway (secs)	Speed (ft/sec)	Link Flow Range (passengers/hr)
1	60 seat bus	150	40	720 – 1440
2	60 seat bus	300	40	400 – 719
3	Walk	0	4	0 – 399

(c) Service Specification

Note: Bus requires 132 sec to cover 1 mile and 228 sec to cover 1.73 mile
Walking requires 1320 sec for 1 mile and 2280 sec for 1.73 miles.
Waiting time assumed to be half of headway. Zero dwell time assume
No transfer if sequential links have some technology.

It is assumed that the individual trip-maker seeks to minimize his own trip time (or, more generally, his disutility) by using a route on which the trip time is less than or equal to trip times on routes not used. Minimum path rather than multiple path assignment is used for two reasons. Transit systems do not, in general, offer a variety of paths between a given pair of origins and destinations. Furthermore, minimum path assignment tends to concentrate flows, which is compatible with the intent of the model. In symmetrical networks, the node numbering system influences the selection of the minimum path; in such cases, node numbering should be done on a random basis and sensitivity checks made.

In the absence of an integrated predefined system of transit routes, obviously some assumptions are required to determine minimum path routes through the evolving network. It is assumed that, if two sequential links currently use the same technology (e.g., rail or bus), no transfer is required even if the frequency of service on the two links differs. If the technologies differ, it is assumed that a transfer is required, and the trip-maker must wait at the transfer point for a period equal to half of the service headway on the second link. The minimum path algorithm used in the model is basically an amendment to the Moore algorithm by Dial (2). The algorithm has been further amended to allow either stopping at stations enroute or continuity of through movement at intermediate stations.

Individual O-D demands are loaded onto links in the appropriate minimum path and summed to give the total flow along each link in the network. The checking routine (step 3) is achieved by referring to the service specification.

The procedure for changing a link's service level can be formulated in a number of different ways. The most obvious is to change the service level of a directed link (differentiating between link $\overrightarrow{A\text{-}B}$ and link $\overrightarrow{B\text{-}A}$) on the basis of its own flow level. This approach may, however, result in links with common nodes being allotted different technology-headway combinations. A second approach is to give to both links (i.e., $\overrightarrow{A\text{-}B}$ and $\overrightarrow{B\text{-}A}$) the service level appropriate to the average loading on the two links. This approach ensures that the two links have the same technology and builds in vehicle "backhaul," which is an operating feature of all real-world transit systems.

By assigning the same service level to both links on the basis of their average loading, the economic use of that service level is ensured. If the link loadings are widely different, however, the demand on the more heavily loaded link could exceed the capacity limit of the assigned service level; i.e., if the capacity limit were based on all seated passengers, this approach could produce some standees. One could equally well give both links ($\overrightarrow{A\text{-}B}$, $\overrightarrow{B\text{-}A}$) the same service level by using the higher of the link loadings as the criterion. This approach satisfies the capacity constraint but may result in violating the economic constraint. Other approaches not currently in the model involve a consideration of the loading on "strings" of links as a basis for allotting service levels.

The evolution of the equilibrium flow condition during the iterations is of interest. After the first iteration, few (if any) links will show correspondence (in the service specification) between the "initialization" service level and link flow levels. Most will therefore be given a lower service level. Some links will not be downgraded as much as others by virtue of the higher flows they attract due to their inherent location and orientation attributes. In the second iteration, new minimum paths will be found that take advantage of the lower times possible via links with a high service level. Loading the O-D demands onto the new minimum paths further increases the level of flow on these links, thus enabling them to acquire a service level of yet higher quality. The enhanced quality of these links makes them even more attractive, and they will be included in more minimum paths in the subsequent iteration. This process of flow concentration will continue until the quality of such links no longer compensates for the extra distance involved in making use of them for the remaining O-D flows. For remaining O-D flows, a lower trip time is possible via a more direct path (although via links with a lower quality service level).

EXAMPLE OF ALGORITHMIC PROCEDURE

A five-link template network is shown in Figure 12a, and the demand to be accommodated is shown in Figure 12b. Suppose that we wish to find the distribution of technologies and service frequencies that derive from the service specification shown in Figure 12c.

In the "initialization" step, all links are given service level 1 as shown in Figure 13a. The minimum time paths are then derived, bearing in mind the assumptions mentioned earlier; the minimum path times are shown in Figure 13b. Loading the trip matrix onto these paths results in the link flows shown in Figure 13c. Reference to the service specification shows that some links should receive different service levels as shown in Figure 13d. New minimum time paths are computed through the amended network, resulting in the times shown in Figure 13e. Loading these minimum paths gives the flow distribution shown in Figure 13f. Once again, the link flow levels are checked against the service specification and the necessary changes in link service level made (Fig. 13g). The resultant minimum path times, which are shown in Figure 13h, lead to the same flow distribution shown in Figure 13f. Because the flow distribution is the same as that in the previous iteration, an equilibrium condition has been achieved. The distribution of hardware systems and service frequencies that are derived from the proposed service specification is shown in Figure 13g.

COMMENTS ON THE MODEL

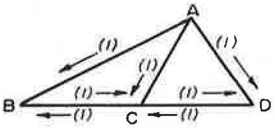
The distribution of hardware systems and service frequencies produced by the service specification model is not necessarily an operational system because the model reaches the equilibrium condition by considering the status of individual links. An operational transit system is actually an integrated set of routes or link sequences. The output of the model must be "operationalized" by the analyst; the adjusted system is then run through a final iteration, which suppresses any further changes of link status, to give the final flow distribution.

Although there is no mechanism in the model for ensuring that a reasonable route structure is produced, it appears (from testing done to date) that relatively little adjustment is required to define an acceptable route structure within the transit system configuration produced by the model, especially for node-oriented systems. This results from the fact that most minimum paths through a uniform quality network pass through or near the center of the network. Central links are thus subject to comparatively higher flows and hence warrant a higher quality of service. The tendency of minimum paths to pass through the central links is thus further emphasized. The result is that link flow levels are high on central links and decrease toward the periphery of the network. This phenomenon, in turn, leads to a gradation of transit system quality in like manner, thus facilitating the definition of a route structure within the transit system.

The preceding discussion has a bearing on the assumption built into the minimum path algorithm, namely, that no transfer occurs if sequential links have the same hardware system. It was mentioned earlier that the trip matrix should represent the morning peak hour—in which case most transit trips will be oriented toward the center of the network. A typical schedule structure, given that the quality of service declines from the center toward the periphery of a network, is shown in Figure 14. The assumption is thus quite acceptable for centrally directed transit trips, hence the reason for specifying a morning peak-hour trip matrix. If an evening peak-hour trip matrix were to be used, the assumption would result in lower trip times than would actually be the case. Various techniques can, however, be adopted to handle this condition.

It is assumed in the current model that technology speed is not influenced by its own loading or by other flows on the same guideway. For rail systems this is acceptable, but buses are influenced adversely by automobile traffic especially in the central areas of a city. The model thus implies that buses operate on a separate right-of-way if automobile traffic is heavy enough to influence bus speed. This deficiency can be overcome by specifying that buses on central links operate at a lower speed.

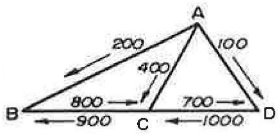
Figure 13. Example of algorithmic procedure.



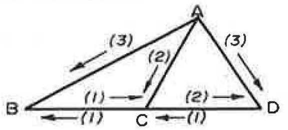
(a) Initialization

to / from	B	C	A
A	AB, 303	AC, 207	AD, 207
B	--	BC, 207	BCD, 339
C	CB, 207	--	CD, 207
D	DCB, 339	DC, 207	--

(b) Minimum Path Travel Times Resulting from Initialization



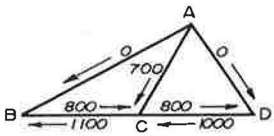
(c) Loading in 1st Iteration



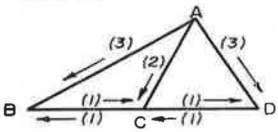
(d) Change of Link Status Sets After 1st Iteration

to / from	B	C	D
A	ACB, 414	AC, 282	ACD, 414
B	--	BC, 207	BCD, 339
C	CB, 207	--	CD, 282
D	DCB, 339	DC, 207	--

(e) Minimum Path Travel Times Resulting from (d)



(f) Loading in 2nd Iteration

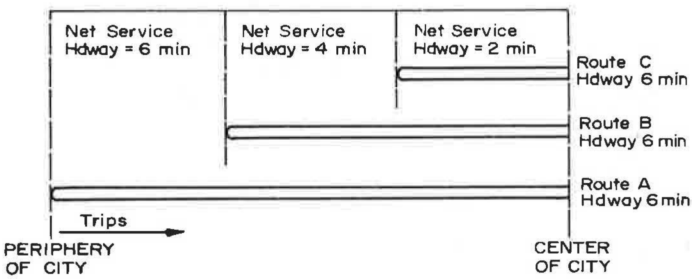


(g) Change of Link Status Sets After 2nd Iteration

to / from	B	C	D
A	ACB, 414	AC, 282	ACD, 414
B	--	BC, 207	BCD, 339
C	CB, 207	--	CD, 207
D	DCB, 339	DC, 207	--

(h) Minimum Path Travel Times Resulting from (g)

Figure 14. Typical schedule structure.



A final comment concerns the manner in which the model realizes the minimization of individual trip times. Theoretically, the model cannot guarantee that an optimum transit network is realized in all cases because of two factors. The first relates to the step structure of the service specification (Fig. 8) and the second to the fact that, in the model, adjustment of a link's status set trails rather than leads the trip assignment step. Preliminary tests of the model, however, indicate that this may not be a serious problem. The built-in dynamism of the model appears to result in a transit network whose redundancy is so reduced that few nearly equal time paths between any origin and destination exist in the equilibrium flow condition.

EXPERIMENTAL RESULTS

A computer program to test the performance of the service specification model was initially written in Fortran IV for use on a CDC 6400 computer at the University of Washington (5). An extended version of the model was later developed for use on an IBM 360-67 computer using a WAT IV compiler at Pennsylvania State University.

Sixteen different template networks, using different hypothetical service specifications and demand patterns, were used in the tests. It was found that the attainment of an equilibrium flow condition was influenced by three factors: the location of the steps in a service specification, the status set used for "initialization" in cases where fixed transit time links are included in the template, and the percentage of nonplanar links in the template.

In most runs, an equilibrium flow condition was produced by the model within (arbitrarily chosen) 12 iterations. In the instances where convergence did not occur, changes in the preceding factors produced an equilibrium condition. In some cases, a pseudo-equilibrium condition developed wherein a repeating cycle of link status changes occurred involving the same small number of links. In cases where a convergent solution was not obtained, the factors previously given were identified as contributing factors.

The model was able to achieve an equilibrium flow condition by using both planar and nonplanar templates. In the latter case, however, increasing the percentage of nonplanar links resulted in nonconvergence within the cutoff number of iterations when using a multiple-origin, multiple-destination trip matrix. The model is also able to handle networks that include single directed links between nodes, i. e., where link $\underrightarrow{m\ n}$ exists but link $\underrightarrow{n\ m}$ is omitted.

Tests and subsequent evaluation indicate that, for planar templates, the service level used for "initialization" does not influence the nature of the resulting equilibrium flow condition. This is not true, however, for networks that contain links whose service level is not influenced by the level of flow across them such as moving belts.

Because of time and monetary constraints, it has not been possible to empirically test and evaluate every possible combination of variables in the model. The range of tests made to date, however, indicates that the concept of the model is feasible and that it promises to be a valuable addition to the array of public transportation planning models.

GENERATING TRANSIT NETWORKS

The service specification determines the structure of the transit network. By varying the formulation of the service specification to reflect different ways of operating a given mix of hardware systems or by changing the mix of hardware systems, different networks are produced. The technologies described in the service specification need not necessarily be existing systems; i. e., they could be hypothetical systems. Such an approach could be adopted to explore the implications of some proposed hardware system or to define performance and economic parameters for a hardware system required to give normative levels of service.

If a template contains fixed performance links, it appears that different transit networks may, in some cases, be generated by establishing the template at different service levels. In this way, one could vary the degree to which a new system complements, or is complemented by, a preexisting fixed quality (belt) system.

CONCLUSIONS

The service specification model is intended as a screening model to explore the wealth of alternative hardware system combinations and operating policies in public transport system planning. As such, it fills a critical gap in the current modeling process. It has been shown that the concepts encompassed by the model are viable and that the model promises to become a practical planning tool.

Although the model has been described primarily in terms of an urban transit application, the model may be used in any transportation context for which a service specification or supply function can be formulated. Further research on the model and an examination of its utility as a planning tool in a real setting are currently being carried out at the Pennsylvania Transportation and Traffic Safety Center, Pennsylvania State University.

ACKNOWLEDGMENT

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