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The Timing Dimension of Urban Transport Decisions*

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Recently there has been a great deal of discussion concerning the need for "balanced" urban transportation systems. Much of this discussion of "balance" is a result of the heightening realization that no one mode and no one investment pattern can solve the growing problem of moving increasing numbers of people into, within, and around the urban regions. In the past, the urban highway engineer, the transit designer, and the city planner have each brought a background, a training, a point of view, and, all too frequently, a commitment to a mode and a methodology which have led to the fragmentation of the urban transport system. Today, as the crises in urban transport intensify, there is greater public and official awareness of the interrelatedness of the various urban transport decisions and the influence of these decisions on how the city functions.

This paper, then, treats some of the economic problems, most particularly the problem of timing, implicit in achieving the sort of balanced urban transport mix that is sorely needed in our cities. Thus, the pricing of urban automobile trips is examined, as is the interaction between transport investment decisions and pricing, on the one hand, and land-use decisions and pricing, on the other. The social costs and benefits and the income effect of transport decisions form a vital link in this chain of interrelated problems. The economies of scale associated with various transport modes are presented in relation to Atlanta, Georgia, a city in the process of making basic urban transport decisions. The model thus constructed can, in a static sense, serve as a guide for determining the proper mix of urban transport modes.

The latter part of the paper utilizes the distinctions made in the static model to examine the problem of optimizing through time. Much of the literature on urban transport decisions, particularly that relevant to rapid transit decisions, focuses on the very largest cities in the nation. But those cities approaching the need for rapid transit comprise a class ripe for consideration, and, as was mentioned above, Atlanta is such a city. Since rapid transit decisions are not "now-or-never" decisions, there is a choice, both in form and timing, among alternative investment programs. These choices will be presented with the aid of a simplified investment model based on the Atlanta experience.

PRICING AND INVESTMENT DECISIONS IN URBAN TRANSPORT

Let us begin by examining the pricing and investment decisions encount-

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ered in developing a balanced transport mix from the static viewpoint of economic theory. Later the model developed will be related to the timing problem.

In the United States there is a predisposition to price as many goods as possible by the market mechanism. Even when the good is not or cannot be produced in the private sector, we often try to secure cost and revenue estimates and to ascertain what the approximate market-determined price would be. Of the several functions that prices perform, the first, and the one which is usually over-emphasized in relation to the others, is the revenue function. The revenue function holds that only those goods and services should be produced whose costs can be recouped by revenues from the sale of the commodity or service. By and large, if a good or service cannot be produced and priced in such a way as to recover the cost associated with production, there is the general presupposition that this good should not be produced.

A second function of price is the allocating or rationing function. Economists see the world as one where scarce resources are matched against almost unlimited demands for goods and services that are produced using these resources. Given in income distribution, prices are the mechanism by which these resources are allocated to the production of particular goods and services in relation to their contribution to production and in accordance with consumer demands. With a given income distribution, prices when working properly should distribute resources to the production of goods and services most wanted by consumers and ration the resulting goods to those consumers having the greatest effective desire for them.

Prices should also perform a third function, that of encouraging the economical use of goods and services produced utilizing scarce resources. If goods or services are priced below the cost to society of producing them, then consumers may not economize in their use.

With these functions performed by price as a background, the pricing and investment decisions leading to the "proper" transport mix can be examined. Initially these decisions must be analyzed in relation to some rather extreme assumptions. Later some of the economic and social complexities encountered when these assumptions are not met will be discussed.

Assume, for the time being, that all goods and services including urban transport are "correctly priced"—that is, perfect competition exists and the price of the products and services is equal to the addition to total cost of producing the last unit. Second, assume that the private costs truly reflect the cost of providing the service and that all benefits accrue only to those buying the service, not to society as a whole. Third, assume that there are no economies of scale, that is, that the average cost of producing transport service does not decrease as the quantity produced increases. Finally, assume a given income distribution.

Under the conditions outlined above the "proper" pricing and hence the choice of investment for transit would be quite simple. Transit would be priced in accordance with variations in costs, with fares geared to the time of day, direction, and distance. Mass transit would be built when the demand for transit service was sufficient to meet all costs of constructing and operating the transit system. An additional unit of transit service would be provided as long as consumers were willing to cover the incremental costs of providing the unit of service. The same type of mechanism would apply to the pricing of automobile trips, with strong implications for those seeking to achieve a balanced transport mix. Urban auto trips would be priced to reflect the actual (incremental) economic costs associated with each and every trip, varying as costs vary with direction, distance, and time of day. If, given this system of prices, the consumers continued to demand larger and larger quantities of peak-period urban roadway capacity, then the signal to highway authorities would be a clear one: additional capacity should be provided. The problem presented to the transport planners would be relatively simple: they could obtain the proper transport mix by making sure that investment decisions responded to market signals.

Unfortunately the job of determining the proper transport mix is complicated because the simplifying assumptions made above do not mirror reality. In the succeeding sections we shall see how some of the complexities that exist because these simplifying assumptions are not met complicate the job of developing a balanced urban transport mix.

Pricing of urban automobile trips

The first assumption, that of "proper" pricing of all goods and services in the economy, is a most heroic assumption. It can be argued convincingly that very few goods are so priced and that this mispricing will, to a lesser or greater extent, have an effect on the urban transport investment decision. Two areas of mispricing affect the urban transport decision process most directly: the pricing patterns for urban auto trips and the pricing (and financing) of housing. Of the two the former is of greater importance.

Much of the mispricing of urban auto trips is related to the costs of providing urban roadway capacity, and most of the distortion in the charges used to recover these expenditures is attributable to the journey-to-work trip. This trip is focused on a certain place, the job site, and a certain time, the customary beginning and ending of the business day. This type of trip generates the morning and afternoon peaks. Wilbur Smith, a prominent consultant, reports on a study of twelve cities which shows that 34 per cent of all home-based trips are journey-to-work trips.[1]* In Atlanta in 1965, 27 per cent of weekday trips were trips between home and work.[2] It has been found that the peak to off-peak ratios on urban expressways tend to be in the range of 2.4 to 2.6 to 1.[3] In 1962, for example, 28 per cent of the daily use of Detroit's Lodge-Ford Expressway, 44 per cent of the use of Memorial Bridge in Washington, D.C., and 29 per cent of the daily use of Congress Street Expressway in Chicago occurred during the four peak hours.[4] In order to try to satisfy this demand for journey-to-work trips, public authorities have made huge expenditures on urban capacity, and this capacity is much in excess of that needed to meet the base or off-peak-period demand for urban automobile travel.

The costs of constructing roadways providing greater capacity to handle additional peak-period urban automobile trips are extremely high. One

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*Footnotes will be found at the conclusion of this article.

transportation researcher, George M. Smerk, reported in 1965 that the average cost per urban mile of a four-lane interstate system highway was $3,658,000.[5] The costs of providing capacity in the larger urban areas tend to be much higher than in smaller urban areas.[6] Thus, in Manhattan one mile of urban expressway is projected to cost over one hundred million dollars.[7] It must be remembered that the additional capacity is needed primarily for the morning and afternoon peak periods. William S. Vickrey of Columbia University has illustrated the high costs of adding this additional capacity in Washington, D.C. He found that by "dividing the extra cost by the extra rush hour traffic, it turned out that for each additional car making a daily trip that contributes to the dominant flow, [sic] during the peak hour, an additional investment of $23,000 was projected."[8]

To construct a mile of Boston's Central Artery Expressway costs some $50,000,000, but construction costs alone understate the economic costs of providing this facility. For example, $16,000,000 worth of property values was removed from the tax rolls due to land clearance needed for the expressway. This represents a tax loss of over $1,000,000 per year.[9] Thus, it is obvious that in addition to the actual cost or money outlay involved in providing capacity for peak periods there are other explicit and implicit costs attributable to the twin-peak nature of urban auto-trip demand. The relevant capacity cost concept, then, includes not only the actual money outlay involved in construction but should also include: (1) the loss of tax revenue from the land that has to be cleared for the additional capacity;[10] (2) the foregone benefits that would have been derived from any city-owned land that is used; (3) an implicit interest figure on the actual investment made; (4) the costs of disrupting established businesses and communities; (5) any decrease in property values due to the roadway project; and (6) the additional costs of street-cleaning and traffic control due to peak-period traffic. Thus, the cost of additional urban roadway capacity that exists primarily to meet peak-period demand is quite large, especially when all the subsidiary costs are added to the construction cost figures.

Urban auto trips are not mispriced, however, just because public costs are high: they are mispriced because the prices paid do not reflect the costs of providing the service. User charges in the form of taxes on gasoline, autos, and to a lesser extent on tires and other automobile equipment are the closest approximation to a price charged for providing roadway capacity. As prices, user charges suffer from the weakness that, since they are imposed by the state and federal governments, automobile trip charges are almost exactly the same for peak and off-peak use, for major-flow and minor-flow directions, and for urban and rural trips. Gasoline and tire consumption are poor estimators of the costs of providing the capacity on which the consumption takes place. It can thus be concluded that user charges do not reflect the costs of any particular trip, since they are a price based on average costs.

There is some doubt as to whether nationwide user charges cover the overall expenditures made for highways, streets, and roads, both rural and urban.[11] There is less doubt, however, concerning the fact that cities spend more on facilities and services than they receive from highway user charges, including federal and state grants. In 1961, when the 43 largest cities in the United States spent $678,000,000 on facilities and services for motor vehicles, highway user receipts including state and federal grants totaled only $307,000,000. Thus, receipts were only 45 per cent of expenditures.[12] Professor Tillo E. Kuhn of UCLA concluded after studying several actual and proposed urban freeways that in no case did revenues from user charges earned by travel over the freeways cover the total costs of providing the freeways.[13]

Even if total user charges did cover the total cost of providing urban road capacity, problems would still exist in the pricing of the urban automobile trip, primarily because present prices are based on average cost and, as discussed earlier, do not take into account the peak, off-peak nature of these trips. If present user charges were generating enough revenue to cover completely the total cost of producing additional capacity, the third function of price would still be violated, that is, the function of economizing in the use of scarce resources. It is undoubtedly true that peak-period users are subsidized, even on freeways with unusually balanced traffic flows and even when extremely conservative costing assumptions are made for the assignment of peak-hour costs per vehicle mile.[14] Dr. Lyle C. Fitch, Director of the Institute of Public Administration, has found the costs of accommodating peak-hour traffic to be between two and three times as much as for the off-peak periods.[15]

The second function of price, the rationing or allocating function, is also violated, again because of the failure of the pricing system to recognize the peak, off-peak nature of urban automobile trips. That prices are too low for peak periods and, thus, capacity is insufficient can be illustrated in no better way than by looking at the problems of congestion during peak periods. In the case of any commodity or service, when price is set at an artificially low level excess demand will occur. Congestion, then, is an excess demand for urban automobile trips.

Congestion should encourage transport planners to examine the entire urban transport system. They must recognize that auto congestion may be a signal for more roadway capacity or for investment in an alternative transport mode, or that it may simply be the inevitable result of mispricing urban automobile trips, a condition, then, that must be endured until such time as additional investment becomes economically justifiable. As in the previously cited case of Washington, D.C., where the cost of increasing capacity was found to be $23,000 per vehicle, automatic investment in additional capacity can be extremely costly.[16] The allocating or rationing function of price may be inoperable to the extent that peak-period congestion moves highway authorities automatically to increase urban road capacity. The result of such an automatic response is an imbalance (or further imbalance) in the urban transport system.

Land use and pricing

Urban trips are only occasionally taken in and of themselves. With the exception of a pleasure ride, most urban trips are undertaken in relation to some consumption or production activity. Since these trips are actually desired "linkages" between and among residences, businesses, and cultural, educational and recreational facilities, they are directly related to the land-use patterns of the community. Land-use patterns are not only functions of existing urban transport patterns and modes, but are also sources generating demand for modal changes. There is a real question, for example, as to whether high concentrations of population and employment must be in existence before the establishment of rapid transit or whether the construction of a rapid transit line in an area will create the necessary market for rapid transit service.[17] There can be little doubt that in the Atlanta case many land-use decisions were directly related to the planning and building of the urban expressway system; in fact, much of the development along the expressway preceded the completion of the system.[18] Again, it will be remembered that these decisions were based on a system of pricing urban automobile trips which did not truly reflect the costs of providing the service. Thus, it was not surprising that parts of the expressway system were exceeding designed maximum capacity by some 22 per cent at peak periods even before the expressway system was completed.[19]

"Incorrect" pricing in terms of urban land use is not limited to the pricing of automobile trips, however. The pricing of residential dwellings has also been subject to some inequities. Post-World War II policies of the Federal Housing Administration and the Veterans Administration favored suburban construction where large lots were available and actually made it almost impossible for loans underwritten by these two agencies to finance construction of the types of housing normally produced in the cities.[20] The loan policies of government agencies during the 1950's also tended to retard or at least not encourage the building of multi-unit dwellings. For example, only 8.5 per cent of all housing starts in 1955 were multiple-dwelling-unit construction.[21] Fortunately, the government and financial communities are becoming much more responsive to the needs of cities, in terms of both single-family and multiple-unit dwellings. This can be illustrated in Atlanta where there has been a large boom in apartment construction in recent years, and where it is estimated that apartment construction will comprise some 35 per cent of all dwelling starts between 1961 and 1983.[22] Thus, mispricing of urban auto trips is compounded by loan policies which encourage migration to the suburbs. The result of this process is a land-use pattern of low density geared to an auto-dominated expressway transportation system.

Private and social costs and benefits of urban transport decisions

One of the simplifying assumptions made above was that all private costs fully reflect the costs to society of providing the service, and that all the benefits of the service accrue to the individual utilizing the service. In reality we find that this is far from true.

Under an auto-dominated transportation system, stores, office buildings, and industrial plants are often faced with the necessity of dedicating extremely expensive land to parking facilities for customers and employees who arrive by auto. Often this service is provided at no cost or at less than the fully allocated cost of providing this service. Yet to the extent that customers and employees use mass transit, employers and merchants can reduce the number of expensive parking facilities needed.

These facts were expressly recognized in Chicago in 1962 when a plant which had moved to the suburbs desired the extension of transit service to the plant site. The Chicago Transit Authority found that there was insufficient patronage to cover the costs of providing service. The plant, however, entered into an agreement with the transit authority that it would guarantee revenues equal to 30 passengers per trip if service were extended. Three morning and afternoon trips were provided, and on the average 133 riders used this service. The cost to the plant was $288.50 per month.[23]

That this company was willing to subsidize transit rides for employees indicates that transit service can and does provide benefits to non-users of the service, in this case the industrial plant. The amount of the transit subsidy was offset in whole or in part by a reduction in the subsidy in the form of parking places for workers arriving by automobile. It is also true that transit service to a plant site expands the labor market available to the firm to include those who do not drive.

Congestion is another area in which the costs to the private individual do not represent the costs of society as a whole. The private costs facing the individual driver as he enters an urban roadway at a time when the effective capacity of the roadway is being fully utilized are the money, time, and psychic costs of making the trip. But the continued addition of automobiles when capacity is fully utilized has the effect of reducing the "product" of the urban roadway, in this case the number of cars that can be carried in a given period of time.[24] The entrance of additional automobiles increases the time, money, and psychic expenditures of automobile drivers already on the roadway. The appropriate costs would, thus, recognize the effect of additional automobiles on users already on the roadway, whereas the private costs take into consideration only the costs incurred by the driver entering the roadway.[25] To the extent that a mass transit system diverts peak-period users to itself and away from expressways operating in excess of their designed capacity, the car-carrying ability of the expressway is increased, and the time, money, and psychic costs associated with auto trips are reduced.

Some of the benefits of transport investment can be estimated explicitly. The Georgia State Highway Department and the U.S. Bureau of Public Roads in 1962 conducted both a home interview "origin and destination study" and a screen-line count. From these studies they arrived at diversion rates for the proposed Atlanta rapid transit system. Projections were made on the basis of these figures up to the year 1983, after appropriate assumptions were made concerning the fare and level of service for rapid transit.[26] It was found in 1962 that of the fourteen major corridors in Atlanta, seven were operating in excess of designed capacity during the morning and afternoon peaks. The study projected chaotic results by 1983 if the city did not change the 1962 urban transport mix, i.e., an auto-dominant expressway system supplemented by a privately operated bus system. On almost all of the corridors, demand for automobile trips would outstrip foreseeable increases in capacity. Indeed, in several corridors the extent of the excess demand over capacity would equal or exceed two to one.[27]

Data from the above-mentioned study were used to calculate some of the economic benefits of the diversion of a percentage of the journey-to-work trips to mass transit. Insurance premiums are less when a person does not use his automobile to commute to work. These savings range from $5 to $15 per driver per year. A very conservative estimate for the overall insurance saving is in the nature of $150,000. Additionally, any reduction in automobile trips would bring about a reduction in automobile accidents. The cost of automobile accidents was estimated at $2,000 for each million vehicle miles. A conservative estimate of the savings due to diversion from automobiles to mass transit would be $160,000 a year, not including the real savings in money and human resources which accrue when fatalities and injuries are reduced.[28] The greatest savings would be in terms of travel time, for both highway and transit users. The total average saving per day was estimated to be 23,400 man-hours. Even if the very nominal rate of $0.85 per man-hour is used, this means a yearly saving of almost five million dollars. This figure makes no allowances for savings in time by those using public transit during off-peak periods and savings in time for truck drivers. If these latter are included, the annual savings due to reduction in travel time can be extremely conservatively estimated in the neighborhood of 6-1/2 million dollars per year.[29]

Other benefits and costs related to transport investment are as evident as some of the foregoing, but are much less easily estimated. For example, tremendous concentrations of automobile traffic during peak periods of the day have as by-products greater noise and air pollution, which can impose upon society certain real costs. An estimated 87 per cent of the smog in Los Angeles results from automobile traffic fumes.[30] That noise has disutility and does impose costs against other members of society is indicated by the increased use of noise-abatement materials in urban construction. To the extent that improved transit diverts patronage away from urban automobile trips, these costs will be reduced.

There are also other important but less easily recognized costs associated with the imposition of additional roadway capacity on the geography of cities. Often huge expressway projects act as ribbons of concrete which Balkanize the urban landscape into isolated islands with very limited channels for egress and ingress. The construction of additional urban roadway capacity often brings about the dissolution of urban communities and the business centers which serve these communities. The physical costs of this process are usually included in the construction costs of the urban roadway; the social costs, the dismemberment of social and business organizations, are seldom fully compensated for. Many cities have experienced what becomes a vicious circle when established neighborhoods are displaced to provide urban roadway capacity for commuters who live in the expanding suburbs. The people who are displaced by the new roadway often add to the flight to the suburbs (which is, among other things, a flight away from the city tax rolls) and, in turn, generate the need for additional roadway capacity. Thus in Atlanta much opposition has developed to a proposed expressway which will dissect the prosperous Morningside area. Residents claim that it will ruin the community, disrupt established social patterns, deny local businessmen much of their normal trade area, and lower property values.

The effect of transport investment decisions on the less tangible but important social systems of the urban area must be considered in determining the proper transport system for the area.

The complexity of developing a balanced urban transport system is illustrated by the fact that the demand for transport is a function of land use and that land use itself is in part a function of transportation patterns and modes. Population, employment, land uses, and transportation are so intricately intertwined that they are inseparable, and a significant change in any one of these factors will affect the others. As was mentioned previously, a large number of residential, commercial, and industrial developments have already taken place in response to the construction of the Atlanta expressway system. In fact, many of these developments preceded the completion of the system in anticipation of the effects of its completion. The same type of response could be expected to the development of a mass transit system: the transit system could become a tool in determining the nature and form of the city.[31]

If the transport mode can and does affect the developmental and land-use patterns of the city, then the urban highway engineer and the transit planner are partially responsible for answering the question of what type of city we should have. The answer to this last question is of utmost importance, not only to the economic and social efficiency of the urban area, but also to the quality of human life in the area. If, for example, additional investment in urban expressway capacity increases urban sprawl and the "shotgun" pattern of development that is typical of many metropolitan areas, then the social and private costs associated with this type of development should be weighed by the decision-makers. If, on the other hand, rapid transit leads to high-density modal developments in the proximity of transit stations and this type of development is more efficient to serve in terms of providing public services, then the benefits of this developmental pattern should be included in the data weighed by the decision-making authorities. Foremost among the social costs and benefits that must be considered in determining the proper urban transport mix are the city-determining aspects of transport decisions.

Income effects of transport decisions

In the model this paper presents for determining the proper investment policy for urban transport, the assumption was made that the distribution of income was given. The determination of the "proper" income distribution is a value judgment and as such is beyond the purview of this paper. It is obvious that the pricing and quality of a publicly consumed service such as transit will have marked effects on the real incomes of individuals within a community.

It is important to note that despite the rapid increase in car ownership in the postwar period, there are some individuals within the community for whom the alternative of automobile trips does not exist. In 1960, 54 per cent of the households with annual incomes of less than $2,000 did not own an automobile and 43 per cent of the households where the head of the household was over 65 years of age did not own an automobile. It was also found that whereas 78 per cent of the households in the United States as a whole owned automobiles in that year, the figure for households in urban communities with a population of over 250,000 was only 63 per cent.[32] It has been pointed out that in the mid-1950's the majority of urban-dwelling women could not even drive a car.[33] Thus, women, the elderly, and the poor often constitute almost captive customers of the public transit system without the alternative of using the private automobile to make urban trips. An increase in the quality and amount of public transit should have the effect of redistributing income in favor of low-income groups. A quality transit system may also increase the number of jobs available to low-income groups residing in the central city.

Economies of scale in urban transport

In striving to achieve a balanced urban transit mix, transportation planners must perforce be interested in the relationship between the cost of the investment and the capacity of the investment to produce urban trips. More specifically, they should be interested in how costs vary as additional trips are demanded and provided. In economics this concept is called "economies of scale." Thus, a discussion of the economies of scale of various modes of urban transport is in order at this point. This discussion will be suggestive rather than exhaustive.

In terms of its ability to produce a large number of trips in a short period of time, rail transit is unexcelled. Estimates of the number of passengers that can be carried per hour by ten-car rapid transit trains operating on ninety-second headways are from 36,000 to 48,000 people per track. By using larger than normal-sized trains and by increasing the loading standard, even higher figures can be obtained, in the neighborhood of 72,000 passengers per hour.[34] The IND division of the New York Subways System has experienced loads of 60,000 or more passengers per peak hour per track.[35] One of the advantages of rail rapid transit is the fact that even at relatively low levels of output, it can cover operating costs including the amortization of rolling stock. In Cleveland, for example, this was accomplished with a maximum peak-period load of 7200 passengers per track. Additional loads can be accommodated by purchasing more rolling stock, increasing the length of trains, and decreasing the headways or the time elapsed between trains. All of this can be accomplished without having to produce additional roadbed capacity and by making only minor adjustments in the size of loading platforms and automatic train-control systems.

Economies of scale similarly pertain to operating motor coaches on grade-separated busways. A single-lane busway, freed from the interference of other vehicular traffic, can, on a non-stop basis, handle 850 buses per hour, seating more than 40,000 passengers.[36] If stops are allowed on the busway corridor itself, then this capacity may be reduced to the level of 9,000 to 13,500 passengers per hour. But the provision of a by-pass lane and several loading points at each bus stop can greatly increase this capacity.[37] In Atlanta a proposed bus system operating on its own grade-separated busway with off-busway collection and distribution may provide an estimated peak-period capacity of 15,000 to 20,000 passengers per hour.[38] Rapid busways mass transit also claims a large degree of flexibility in that additional trips can be produced by the same alternatives available to rapid rail transit—that is, increasing the number of buses operating, decreasing the headways between buses, or increasing the loading standards. Once the grade-separated busway is in existence, additional trips can be generated by purchasing additional rolling stock and with minor outlays for increasing the size of pick-up and distribution points. Thus, it can be seen that in the case of both rail rapid transit and buses operated on exclusive grade-separated busways, additional trips can be generated with relatively modest increases in investment and operating costs.

In contrast to the economies of scale encountered with rail rapid transit and urban busways, there are indications that urban roadway capacity can be increased only by incurring more than proportional increases in construction costs. Fitch commented after conducting an extensive study for the U.S. Department of Commerce and the Housing and Home Finance Agency that "actual observation indicates the wider an urban roadway, the greater the cost per land mile."[39] He explains these higher costs primarily by the fact that wider roads tend to occur in more densely settled areas, that right-of-way acquisition costs rise as the width of the roadway increases, and that the cost of intersections and access tend to increase in geometric proportion to the width of the roadway.[40] This observation is consistent with the data on construction costs presented earlier. The designed capacity for an expressway lane, the highest rate of movement without congestion, is in the neighborhood of 1200 to 1700 automobiles per lane per hour. The absolute capacity of an expressway lane has found to be approximately 2000 vehicles per lane per hour. Given the typical loading standard for automobiles of 1.5 at peak periods, the capacity of an expressway lane is in the range of from 1800 to 3000 people per hour depending upon local circumstances and expressway design features.[41] In Atlanta, for example, the designed capacity per lane for the North Expressway is 1500 vehicles per hour.[42]

Thus, from the above discussion we can conclude that the per-lane or per-rail carrying capacity for grade-separated bus operations and rail transit much exceeds the carrying capacity of an expressway lane, and in addition that economies of scale obtain for the first two transport modes, up to very large numbers of passengers carried. The economies of scale associated with mass rail and grade-separated bus urban transport and the diseconomies of scale associated with increasing expressway capacity must be recognized by urban transport planners and public decision-making authorities whose responsibility it is to provide urban areas with a balanced transportation system.

The Atlanta case

In Atlanta it was recognized as early as 1953 when the expressway network was being built, that the six expressways and downtown connector supplemented by a circumferential expressway system would be insufficient to meet projected traffic needs. In 1959 the Atlanta Region Metropolitan Planning Commission, representing the City of Atlanta and the five county governments in the metropolitan area, concluded in its "Crosstown and By-Pass Expressways" study that without rapid transit, by 1970 Atlanta would need an estimated 120 radial expressway lanes including a 28-lane downtown connector.[43] By only 1958 the north leg of the expressway system, which has six lanes, had sufficient traffic to justify ten additional lanes.[44] It is inconceivable that city planners would even consider carving out of the core of the city 120 expressway lanes, 28 of them comprising a downtown connector. In 1965 it was estimated that the average cost per urban mile for a four-lane interstate system was $3,658,000.[45] In 1960 the Atlanta Region Metropolitan Planning Commission estimated the cost of a six-lane expressway at $6,000,000 per mile.[46] This would mean that the needed 120 expressway lanes would cost $120,000,000 per mile, not even including the special costs associated with the connector. Even if the construction of sufficient expressway capacity would not decimate the city, there can be no question but that Atlanta could not afford the expressway alternative.

It is apparent, then, that the Atlanta Region Metropolitan Planning Commission had to explore turning to rapid transit to help solve Atlanta's mounting transport problem. One can also understand the involvement of various other agencies: the City of Atlanta, the counties in the Atlanta metropolitan area, the privately owned Atlanta Transit System, interested business organizations, and the State of Georgia.

Plans for attacking the transport problem have developed along two lines. First, the General Assembly of the State of Georgia set up the Metropolitan Atlanta Rapid Transit Authority (MARTA). This authority has been studying costs and engineering problems of a rail-based rapid transit system. They see a completed system of some 64.9 miles, including 43.8 built at grade, much of it utilizing redundant right-of-way of the railroads which bisect the central Atlanta area; 14.3 miles of aerial structures; and 6.8 miles of subway structures. This system would be built over a period of some 16 years with the initial 21 miles in operation by 1976, some 30 miles in operation by 1978, 37 miles by 1980, 54 miles by 1983, and the completed system by 1985. The total cost estimate based on 1967 prices is $421,000,000. This figure includes all costs of structures, stations, track, utility relocation, electrification, train control, yards and shops, and right-of-way, plus allowances for engineering and contingencies; but no allowance is made for inflation. MARTA plans to finance this system through additions to the property tax in the five-county area and hopefully with the aid of some federal grants.[47]

The second plan which has been proposed to help alleviate Atlanta's urban transport problem is the plan proposed by the Atlanta Transit System. Pointing to the long delays experienced by other cities building rail rapid transit, the Atlanta Transit System proposes as an interim solution a rapid busways system consisting of five radial grade-separated bus lanes in a network of 67 miles. The total cost of the proposed system, which could be made operational in a period of from three to four years, is $52,185,000. Of this figure, some $22,000,000 represents construction costs of the busway, with the remaining $30,000,000 allocable to right-of-way acquisitions.[48] The busway, however, plans to utilize primarily the same redundant rail lines which would be utilized by the rail rapid transit system. Thus, the $30,000,000 spent on right-of-way acquisitions to put the busway into operation would be an initial investment in terms of right-of-way costs for the rail rapid transit system. A commanding feature of the rapid busway proposal is that it offers the possibility of having a relatively high-capacity mass transit system in a relatively short period of time and allows the land-use patterns based on transport improvement to begin much sooner.

The decision rule

Under the simplifying assumptions made originally, the investment decision as to the proper transport mix would be an easy one: additional investment in capacity would be made in each mode as long as consumers were willing to pay the addition to costs of providing that capacity. We found, however, that since user charges did not transmit the nature and extent of cost variations implicit in providing urban automobile trips, transportation planners could not automatically respond to increases in demand for roadway capacity. The interrelatedness of land use and transportation decisions and certain financing practices in this area reinforces this conclusion.

We also found that the benefits and costs associated with providing additional capacity did not accrue to and were not borne solely by those directly utilizing the facility. The costs and benefits should be identified and, where possible, their values estimated. In some cases, real social costs and benefits can be identified but are difficult to quantify. Foremost among this latter group is the influence transport decisions have on the shape of the city. In this case it would appear proper to use transport investment as a tool in "shaping" the type of city which will best serve the needs of its citizens, rather than subverting city functions because of improper transport planning.

It was also found that in the general case and for Atlanta specifically, economies of scale characterize mass transit forms, whereas diseconomies of scale are likely when additional roadway capacity is provided. How costs vary when the need arises to produce more transport service is of prime importance to the transport planner.

Thus the simple decision rule presented earlier must be broadened to take into account the complexities we have discussed. Given present pricing forms for urban automobile trips, the relationship between transport investment and land-use patterns, and the nature and extent of economies of scale in urban transport, additional transport investment in any mode should be made when the increased benefits from the investment (to whomever they derive) exceed the costs of making the investment (to whomever these costs accrue). Those benefits and costs that cannot be quantified must therefore at least be explicitly recognized. In the next section the timing dimension of alternative investment decisions will be discussed.

PLANNING, STRUCTURE AND TIME

The first portion of this paper has developed a static economic model for the consideration of urban transport investments. It has discussed some of the important and difficult problems to be faced in defining the costs and benefits of such investments. These problems usually require much data to initially define the system being analyzed. It is then necessary to estimate from these data and projected data the needs of the urban transport system. It is the problem of meeting these needs over time that we are concerned with here: What alternative investments should be made and when?

Although it is helpful to analyze the alternatives, to construct a rapid transit rail system or not to construct a rapid transit rail system, these are not really the viable alternatives for the urban planner. Urban transport investments are not "now-or-never" decisions.[49] The urban framework is dynamic, and therefore the **when** of capital investment decisions becomes very important. Despite much lip service paid to dynamic decision-making, we nevertheless often make only static, now-or-never comparisons of alternatives. The analysis presented here describes two types of timing problems confronting the urban transportation planner and proposes models for analyzing these two problems.

The postponement of implementation

In some of the early analyses performed relative to a rapid transit rail system for Atlanta, the question seemingly asked was the static one: Does Atlanta need this system now? Many smaller cities are now reaching the point at which Atlanta found herself in the late 1950's and should be planning for the time when they will need to make large-scale expenditures.

When the timing question is considered, the one very narrow alternative—implement rapid rail transit—generates a large number of possible actions within itself. The real options are: implement rapid transit now, vs. 1 year hence, vs. 2 years hence, etc. For example, using a 20-year planning horizon, it is possible to consider alternatives

$$X_{i0}, X_{i1}, X_{i2}, \ldots, X_{i20},$$

where X_{it} is the decision to implement plan i in the year t. This type of decision faces the urban planner because many of the factors determining the urban environment change with time. There are real costs and benefits associated with postponing the implementation of transit alternatives. If the implementation of an alternative is delayed, land-use patterns change, the volume of transportation demand shifts geographically and changes in magnitude, the real cost of right-of-way (ROW) may rise, and economic benefits derived from earlier implementation are lost. On the other hand, the resources may be used during the delay period to derive other benefits. With respect to ROW, for instance, a multi-million-dollar building, the Life of Georgia Building, has been constructed in Atlanta on the ROW that was originally proposed for rapid transit. This is only one simple example of how cost structures are altered and even whole alternatives discarded or radically changed.

The decision makers' postponement decision is based on:

(1) the opportunity gains from postponement

(2) the cost of continuing the present facilities

(3) the change in the cost of implementation

(4) the benefits lost by postponement

(5) the change in salvage value at the end of the planning horizon.

These incremental changes must be weighed by the planner in making the timing decision.

The model presented in word form above is presented mathematically in Appendix A and employs the net present value criterion for investment decision-making.

This timing model emphasizes the quantitative results of project delay through time. It is a planning logic that growing metropolitan areas may use to analyze when capital investments in transport facilities should be undertaken, based on their estimates of the input parameters. As outlined in the first part of this paper, inputs necessary in such a decision do include some very difficult estimates and assumptions, but by employing such a model and using a computer, the urban planner is better able to see the effects of these estimates and assumptions through a sensitivity analysis performed with the computerized model.

In some instances the effects of project delay may be positive and in other instances negative. Explicit consideration of timing allows planners to more forcefully point out the results of delay. It also allows urban areas pressed for resources to examine timing delays so that much-needed funds will not be committed too early and thus other opportunities lost.

Again as was pointed out previously, there may be other results of project delay that are difficult to quantify, but these may be stated and weighed against changes in quantitative results. For instance, some delay may enable the project to take advantage of improved technology. The main point, however, is that time is an important variable in aligning urban investment priorities.

The interim-action model

The model presented above implicitly assumes that during the period of project delay the existing facilities will be operated and maintained. However, other interim actions often exist which require new investment and operating costs that may precede the installation of a large rapid transit rail system.

As an example, again consider the Atlanta situation. Due to the very large transport demand it seems feasible to consider some action other than attempting to maintain existing facilities to meet this transport demand before a rail rapid transit system is implemented. In the particular case of Atlanta, as presented above, a rapid busways proposal has been offered.

Such proposals for interim action can be most efficiently carried out if they are analyzed as a portion of a total alternative including both the interim action and the system proposed to follow this interim action. This type of alternative will be referred to as a compound alternative.

For example, expenditures for ROW, structures, etc., may not seem justified when attributed solely to an interim action, but higher initial expenditures may be the most efficient when analyzed as part of a compound project. On the other hand, a city having a great demand for its resources in areas other than transport may find postponing large capital outlays and accepting a less capital-intensive interim action to be more effective.

The model formulated below illustrates the relationships that should be considered and points out some important aspects of the decision problem. The analysis of compound alternatives is more complicated because they have more decision variables. The time dimensions of the compound alternative are illustrated in Figure 1.

The figure above shows graphically the interrelated decisions the planner must make. The notation used in Figure 1 is defined as follows:

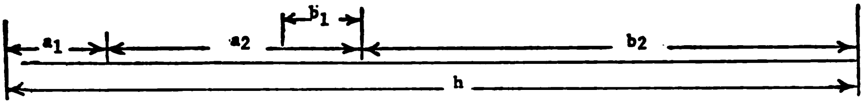

FIGURE 1 Compound Alternative Planning Horizon

h = the length of the planning horizon being considered;
a_1 = the length of time necessary to implement an interim measure A;
a_2 = the length of time which the interim measure will be operated;
b_1 = the length of time necessary to implement the second action (B);
b_2 = the length of time in the planning horizon during which action B will be operated.

Note particularly that actions A and B are made up of two time periods. The real costs over time associated with implementing this compound alternative will be considered as a function of the length of time a_1. The longer a_1 becomes, the more capital-intensive the interim action A. This method of defining cost and benefit structures simply points out that for each "general" compound alternative i, made up of actions A and B, there may be a number of different expenditure patterns to accomplish the alternative. The urban planner must decide how capital-intensive action A will be and how long action A will be operated. These choices then determine b_1 and b_2 for the follow-on action B. The planner must weigh the value of increasing the scale or capital intensity of his interim actions. If he does not do so, then he is certainly suboptimizing over his planning horizon. Indeed this type of analysis requires some very difficult decisions and extensive calculations. For every a_1 (scale variable) chosen, the operation period a_2 must be determined, but with computers many of these calculations can be carried out in a very short period of time. Formulating alternatives and specifying cost structures is difficult, but such action provides a great deal of information for the planner who must meet long-range problems and be prepared for longer lead times on highly capital-intensive projects and actions.

Long-range planning data and analysis, as complex as it may be, does provide a city and its population with projections they may use in making their decisions, and thereby helps determine city patterns. That the city-determining aspects of transport decisions are often explicitly recognized can be exemplified by a statement made in a recent Atlanta regional transportation study: "New patterns of living for people within the Atlanta region will emerge upon the completion of a rapid transit system—or even in anticipation of such a system. Such a system will demand and create an efficient grouping of residences and commercial and employment centers."[30] Long-range planning and well conceived interim action enables the community to form these anticipations and, thus, work toward future benefits.

The interim-action model has been described only generally here and is more formally presented in Appendix B.

SUMMARY

The first part of this paper presents a basic static model developing the economics of urban transport investment decisions, giving special attention to the pricing of urban auto trips, the difference between public and private costs and benefits, and the economies of scale of various transport modes. The model emphasizes the relationship between transport investment decisions and land-use decisions.

Later sections treat time as a dimension in securing the proper transport mix. Two models have been presented for the explicit consideration of the quantitative costs and benefits of transport decisions. These long-range planning models are particularly concerned with exploring the timing of transport investment: When should a plan be implemented and how does an interim action affect the over-all efficiency of a compound alternative? These are the questions being investigated.

It is not the position of this paper that such analyses are simple matters. Transport decisions are seldom made, nor should they be, on the basis of the quantitative comparison of two numbers. However, these quantitative aspects can be used by the planner to establish the possible tradeoffs between the quantitative and qualitative aspects of various transport plans.

FOOTNOTES

1. Wilbur Smith and Associates, *Future Highways and Urban Growth* (New Haven: Wilbur Smith and Associates, 1961), p. 83.
2. Atlanta Region Metropolitan Planning Commission, *Rapid Transit for Metropolitan Atlanta*, Atlanta Metropolitan Region Special Report (September, 1967), p. 1.
3. Smith and Associates, *op. cit.*, p. 93.
4. J. R. Meyer, J. F. Kain, and M. Wohl, *The Urban Transportation Problem* (Cambridge: Harvard University Press, 1965), p. 70.
5. George M. Smerk, *Urban Transportation: The Federal Role* (Bloomington: Indiana University Press, 1965), p. 187.
6. The authors of *The Technology of Urban Transportation* report on a Chicago study which found that the cost of freeways with 4 lanes in each direction varied according to a straight line from $14,000,000 per mile with a net residential density of 180,000 persons per square mile, to $1,000,000 when the net residential density was 0 persons per square mile. See Donald S. Berry, George W. Blomme, Paul W. Shuldiner, and John Hugh Jones, *The Technology of Urban Transportation* (Evanston: Northwestern University Press, 1963), pp. 4-5.
7. U.S., Congress, Senate, Subcommittee of the Committee on Banking and Currency, Hearings, Urban Mass Transportation, 87th Congress, 2d Sess., 1962, p. 289.
8. William S. Vickrey, "Pricing in Urban and Suburban Transport," *American Economic Review*, LIII (May, 1963), 456.
9. "Rail Transit: What's Ahead?" *Railway Age*, CXLIX (October 17, 1960), 18.
10. The automobile is extremely "hungry" in relation to space. For example, one automobile takes up about the same space as an urban office. See Gilbert Burck, "How to Unchoke Our Cities," *Fortune*, LXIV (May, 1961), 119. The implications in terms of land use can be illustrated by reference to the Central Business District of Los Angeles, where 28 per cent of the land area is used for streets, freeways, and service. An additional 38 per cent is used for off-street parking and loading. Seymour S. Taylor, "Freeways Alone Are Not Enough," *Traffic Quarterly*, XIII (July, 1959), 356-357. Over half of the downtown Atlanta area is devoted to streets and parking facilities, and this figure does not include

the 8,707,000 square feet used for expressway right-of-way in the immediate vicinity of the city's core. If this expressway right-of-way and the fringe parking area which abuts the core are included, then Atlanta approaches the Los Angeles proportion of two-thirds of the downtown area being devoted to accommodating motor vehicles, either moving or stored. See Atlanta Region Metropolitan Planning Commission, *Atlanta Region Comprehensive Plan: Rapid Transit* (June, 1961), p. 7.

11. For example, see Lewis M. Schneider, *Marketing Urban Mass Transit* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1965), p. 46, and Fitch, *op. cit.*, pp. 31 and 255.
12. Lyle C. Fitch and Associates, *Urban Transportation and Public Policy* (San Francisco: Chandler Publishing Company, 1964), p. 138.
13. Tillo E. Kuhn, *Public Enterprise Economics and Transport Problems* (Berkeley: University of California Press, 1962), pp. 189-209.
14. Meyer, Kain, and Wohl, *op. cit.*, p. 74.
15. Fitch, *op. cit.*, pp. 134 and 265.
16. Vickrey, *op. cit.*, p. 456.
17. Atlanta Region Metropolitan Planning Commission, *What You Should Know About Rapid Transit* (September, 1960), p. 12.
18. *Ibid.*
19. Atlanta Region Metropolitan Planning Commission, *Atlanta Region Comprehensive Plan: Rapid Transit* (June, 1961), p. 8.
20. Smerk, *op. cit.*, p. 39.
21. Meyer, Kain, and Wohl, *op. cit.*, p. 112.
22. Atlanta Region Metropolitan Planning Commission, *Rapid Transit and Metropolitan Atlanta*, Atlanta Metropolitan Region Special Report, (September, 1967), p. 2.
23. Schneider, *op. cit.*, p. 75.
24. This is analogous to the situation found in the negative-returns stage of a total product curve.
25. The history of economic analysis of problems related to congestion is a long and important one. The present treatment is only suggestive rather than extensive. See A. C. Pigou, *The Economics of Welfare*, 4th ed. (London: Macmillan and Co., Ltd., 1932), pp. 174-196; Frank H. Knight, "Some Fallacies in the Interpretation of Social Cost," *Quarterly Journal of Economics*, XXXVIII (August, 1924), 582-606; and J. M. Buchanan, "Private Ownership and Common Usage: The Road Case Re-examined," *Southern Economic Journal*, XXII (January, 1956), 305-316. For more recent discussions of congestion see Fitch, *op. cit.*, pp. 126-129 and 142-146; Smerk, *op. cit.*, pp. 59-81; and Herbert Mohring and Mitchell Harwitz, *Highway Benefits: An Analytical Framework* (Evanston: Northwestern University Press, 1962), pp. 76-90.
26. Metropolitan Atlanta Transit Study Commission, *A Plan and Program of Rapid Transit for the Atlanta Metropolitan Region*, Report to the City of Atlanta (December, 1962), pp. 92-93.
27. *Ibid.*, pp. 108-109.
28. *Ibid.*, pp. 109-110.
29. *Ibid.*, p. 111.
30. "Coast-to-Coast Race Without Gas," *Business Week*, August 24, 1968, p. 87.
31. Atlanta Region Metropolitan Planning Commission, *What You Should Know About Rapid Transit*, p. 10.
32. Committee for Economic Development, Research and Policy Committee, *Developing Metropolitan Transportation Policies: A Guide for Local Leadership* (New York: The Committee for Economic Development, 1965) p. 25.

33. Robert L. Banks and E. L. Tennyson, "Greater Productivity: Key to the Transit Paradox," *Public Utilities Fortnightly*, LX (July 18, 1957), 74.
34. Walter S. Rainville, Jr. and Wolfgang S. Homburger, "Capacity of Urban Transportation Modes," *Journal of the Highway Division, Proceedings of the American Society of Civil Engineers*, LXXXIX (April, 1963), 48-49.
35. Berry, Blomme, Shuldiner, and Jones, *op. cit.*, p. 45.
36. *Ibid.*, p. 44.
37. *Ibid.*, p. 44, and Rainville and Homburger, *op. cit.*, pp. 48-49.
38. Atlanta Transit System, Inc., *Rapid Busways*, n.d., p. 5.
39. Fitch, *op. cit.*, p. 132.
40. *Ibid.*, pp. 132-133.
41. Meyer, Kain, and Wohl, *op. cit.*, p. 69, and Rainville and Homburger, *op. cit.*, pp. 47-48.
42. Atlanta Region Metropolitan Planning Commission, *Comprehensive Plan . . .*, p. 8.
43. Atlanta Region Metropolitan Planning Commission, *Crosstown and By-Pass Expressways*, Expressway Policy Report No. 2 (June, 1969), pp. ii-iv.
44. *Ibid.*, p. iv.
45. Smerk, *op. cit.*, p. 187.
46. Atlanta Region Metropolitan Planning Commission, *What You Should Know About Rapid Transit*, p. 27.
47. Atlanta Region Metropolitan Planning Commission, *Rapid Transit for Metropolitan Atlanta* (September, 1967), pp. iv-v.
48. Atlanta Transit System, Inc., *Rapid Busways*, p. 20.
49. Stephen A. Marglin, *Approaches to Dynamic Investment Planning* (Amsterdam: North-Holland Publishing Company, 1963).
50. Atlanta Region Metropolitan Planning Commission, *What You Should Know About Rapid Transit*, p. 10.

APPENDIX A

The Effect of Project Timing

A mathematical statement of the project delay model based on the net present value (NPV) criterion is:

$$\mathrm{NPV}_i(k) = \sum_{t=k}^{t=h} \frac{B_{it}}{(1+r)^t} - \sum_{t=k}^{t=h} \frac{C(k)_{it}}{(1+r)^t} - \sum_{t=1}^{t=k} \frac{\overset{\Lambda}{C}_{i,\,t-1}}{(1+r)^{t-1}}$$

$$+ \sum_{t=1}^{t=h} \frac{\overset{\Lambda}{C}_{it}}{(1+r)^t} + \frac{S(k)_{ih}}{(1+r)^h}$$

where the variables are defined as follows:

i = The i^{th} project or alternative
t = The time period
k = The point in time at which the project is implemented
h = The number of time periods in the planning horizon
r = The discount rate

$NPV_i(k)$ = Net present value of project i if implemented at time k.

B_{it} = Benefits derived from project i in the time period t.

$C(k)_{it}$ = Costs of implementing and operating project i in time period t if project i is implemented at point k in time.

$\hat{C}_{it}$ = Costs of continuing the present conditions.

$S(k)_{ih}$ = Salvage value of project i at the end of the planning horizon if project i is undertaken at point k in time.

The deterministic model presented above uses a finite time horizon h and assumes discrete cost and benefit flows. The investment analyst would compare $NPV_i\ (k+1)$ with $NPV_i(k)$.

In the model above all flows are assumed to occur at the end of the relevant time period.

If $NPV_i(k+1) - NPV_i(k) > 0$ then the project should be delayed.

IF $NPV_i(k+1) - NPV_i(k) < 0$ then the project should be undertaken at $t=k$.

APPENDIX B

The Interim Action Model

A mathematical statement of the interim action model described in the text, based on the net present value investment criterion, is:

$$NPV(a_1, a_2)_i = \sum_{t=1}^{t=h} \frac{B(a_1,a_2)_{it}}{(1+r)^t} - \sum_{t=1}^{t=a_1+a_2} \frac{CA(a_1)_{it}}{(1+r)} - \sum_{t=a_1+a_2-b_1}^{t=h} \left(\frac{CB(a_1)_{it}}{(1+r)^t}\right)$$

$$+ \sum_{t=1}^{t=h} \frac{C_{it}}{(1+r)^t} + \sum_{t=1}^{t=h} \left(\frac{SA(a_1,a_2)_{it}}{(1+r)^t} + \frac{SB(a_1,a_2)}{(1+r)^t}\right)$$

where the variables are defined as follows:

i = The i^{th} general compound alternative

t = Time period

h = Length of the planning horizon ($h = a_1 + a_2 + b_2$)

a_1 = Length of time necessary to implement interim action A (used here as a measure of scale for action A)

a_2 = Length of time interim action A will be operated

b_1 = Length of time necessary to implement the follow-on action B

b_2 = Length of time in the planning horizon during which action B will be operated

r = Discount rate.

$NPV(a_1,a_2)_i$ = The net present value of alternative i if implemented in length of time a_1 and operated for a time a_2

$B(a_1,a_2)_{it}$ = The benefits derived from alternative i in period t given a_1 and a_2

$CA(a_1)_{ti}$ = The cost structure of interim action A given a_1

$CB(a_1)_{ti}$ = The cost structure of follow-on action B given a_1

C_{it} = The costs of continuing the present facilities

$SA(a_1,a_2)_{it}$ = The salvage value of interim action A taken in period t, given a_1 and a_2

$SB(a_1,a_2)_{it}$ = The salvage value of follow-on action B taken in period t, given a_1 and a_2

The deterministic model presented above employs a finite planning horizon h and assumes discrete cost and benefit flows. Note that the functional relationships are defined in terms of a_1 and a_2. This results from the assumption that decisions determining a_1 and a_2 determine b_1 and b_2 for a given compound alternative.

The analyst must determine the scale of action A and decide how long action A should be operated. Denote possible a_1 by a_{1j} where j is an integer and possible a_2 by a_{2z} where z is an integer. Given an a_{1j} the analyst must first compare $NPV(a_{1j},a_{2z})_i$ for each possible z, thereby locating an optimum operating period for a given scale a_{1j}. This procedure is continued for each possible a_{1j} and then a comparison of the optimum for each a_{1j} can be made to determine an overall optimum.