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Foreword

The contents of this RECORD emanate from a rather unique session sponsored by the Department of Urban Transportation Planning's committee on Future Concepts at the Highway Research Board's 47th Annual Meeting. A European type session was held at which the formal papers contained herein were reviewed by Dr. Siegfried M. Breuning, Chairman of the Future Concepts Committee. This was followed by a panel discussion of people knowledgeable in the field. Authors present at the session were given the opportunity to comment and react to various points and issues that were raised.

In light of the fact that all six papers are printed in their entirety in this RECORD and that comments on the relevant parts of each are made by Dr. Breuning in his paper entitled, "Future Concepts of Urban Mass Transportation," readers would be well advised to acquaint themselves with the contents by reviewing Dr. Breuning's summary. Papers presented in this RECORD include a discussion of modal split techniques, computer simulation techniques for demand-scheduled bus systems, varying concepts and techniques to improve urban mass transportation, and also visual criteria as they pertain to transit design.

Contents

Future Concepts of Urban Mass Transportation—An Overview

SIEGFRIED M. BREUNING, Massachusetts Institute of Technology

•THIS paper presents an overview of the general concepts of future urban mass transportation. It is part of the general report, given at the Highway Research Board Annual Meeting, in which the six papers published in this RECORD were abstracted and presented for discussion. Since these six papers are given here in their entirety, only comments on relevant parts are being included in this overview.

"Future concepts" of any form of transportation is a rather elusive subject. Some think of it as new gimmicks for cars; others see in it the return to mass transit. Some think people should move back to the city, and others visualize longer and faster movement in personal capsules that move swiftly and cheaply in three dimensions through space. The generality of the topic covers all these ideas, but it also makes it difficult to focus sharply and critically on the real possibilities of the future.

PURPOSE AND GOAL

In the past very few years, it was good enough to make people think about new ideas in transportation. Transportation had been stagnant for so many years that even the idea of change itself was novel. By now transportation innovation has become a household word and our news media are flooded with new technology, the "catchier" the better. We must now move on to the next step in innovation, in which we will begin to assess in some detail the value of new ideas in relation to the needs for transportation. At this state of the art, we hope that our current discussion will not merely contribute more new ideas, but will also bring them into perspective in relation to their usefulness for real improvements in the future.

When considering future concepts in urban transportation, one often expects a preoccupation with or a juxtaposition between expressways and rail rapid transit. In order to reverse this somewhat traditional trend, the papers given under this topic were intended to focus on the broad, future spectrum of urban mass transportation. It is quite clear that urban transportation can involve more than just expressways or rapid transit, or a combination of the two. Other forms of transportation must be seriously considered, and still others may have to be developed from existing modes or recognizable needs.

While much of our present concern stems from today's immediate problems, we do not wish to be overwhelmed by them alone. Additional, formidable problems will arise and we must attempt to foresee them. It is important that as new concepts are forming, we plan not only for their appropriate use tomorrow, but also for their appropriate use throughout their useful lives, whether they be a few years or a few decades. In this set of papers then, we are concerned with any contribution to future concepts of urban mass transportation, be they existing modes or new systems, new software ideas, or new approaches to current problems.

THE BASIC NEED

To make a success of urban transportation we need more than token improvement; we need a new system which eliminates the current problems and failures. We need a large improvement. Maybe we need new technology; maybe we need new operating

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Paper sponsored by Committee on Future Concepts and presented at the 47th Annual Meeting.

policies. People will not want to pay more for transportation in the future so our solutions must be economical. What we need to know is what people really want and need.

I, for one, like my car. If you want me to use a transit vehicle, it will have to be made a lot more attractive than it presently is; it will have to come much closer to my residence, and I will have to be notified as to when that transit vehicle is running and where it is going, and it will have to take me to my destination as fast as my car would.

While I desire much better public transit, I also want improved facilities for ordinary auto driving. I would like to be able to travel without congestion and strain, to park closer to work or shopping, and also to stop acting as chauffeur for the rest of my family.

Neither transit nor the automobile gives me all that I want. Either system would require great improvements to be able to offer me what I think I would want from a good transportation system. Yet we still may not know exactly how to define "improvement." Learning this is one of our most important objectives.

For the last fifty years or so, the transport user has consistently chosen the automobile when given a choice. I suspect that many of the people who are proposing new transit systems do not plan to use them themselves, but rather want to remove some of the other people from the highway so they will have a little more room for their own cars. But this is not a very realistic way to solve the problem. As a matter of fact, this approach perpetuates the problem with a sizable expenditure of funds. The basic difficulty with this unfortunately very common approach to today's traffic problems is the difference between individual goals and social goals. As an individual transport user, one pursues his own individual goals independent of his perception of the societal goal; i. e., car for him, transit for all others, regardless of the willingness of all others, society, to individually accept these social goals. We readily disregard that social achievements in a free society such as ours are by definition an average, or summary of individual goals. As each individual decides on his best solution he also contributes to a social solution, whether or not it is generally acceptable.

We can identify some approaches toward improving both auto and transit to make them more attractive, either socially for the car or individually for transit. Transit must be attractive to individuals or no one will use it. We have to give it greater speed in order to make it consistently capable of speeds equal to or greater than those of the automobile. Door-to-door service is another must. The automobile provides it, and I consider it extremely important, even if I have to walk half a mile from the parking lot. This walk is preferable to one to and from a bus station because it leads directly to the car and to the start of the trip, without the probability of a long wait for a bus. I want service at my convenience, not at the time the transit scheduler has chosen. I also want privacy, comfort and convenience—economically. This is a pretty big order for improving transit service, and to attain these goals requires a lot of work before all or even a good number of them are satisfied. On the other hand, driving in rush-hour congestion is distasteful to most people and parking in remote lots at substantial cost can become a strong deterrent to automobile use in dense areas. A resolution of these problems of the private car would improve the attractiveness of the car immensely.

It would seem then, that if we could combine the advantages of the individual transportation system (the auto) with those of a mass transit system, a viable solution for the future might result. To reach this long-range solution we might in the meantime provide partial improvements which would in some appropriate cases, like downtown, attract people to transit and away from their automobiles. In areas such as the suburbs, we might improve automobile service to offer better access to the nondriver.

In each case, it will take more than a marginal improvement to attract and hold new patrons. Otherwise, any subsequent improvements in another mode might just attract them back to that mode in a vicious, competitive seesaw. For instance, substantial improvement in transit service, where that is advantageous, must be better than what patrons can get or could even expect to obtain from the automobile. This does not mean stamping out the automobile altogether. It means developing the automobile and its improvements in those areas it serves best, and transit in the other areas. As we do this, we should also provide ample opportunity for these two major urban transport systems to interact effectively now and even to merge into one eventually.

PAPER REVIEW

Let me now relate the ideas given in the papers presented in this RECORD to the goals and direction towards future urban mass transportation. I should like to begin the discussion of the papers by outlining one we do not have: one on the user's demand for transportation services. When the materials on the problems of urban mass transportation were being assembled, both a study of basic transport demand and the social questions of what people require in a transit system were unavailable. We mention this omission to point out a relevant and important area in which much work still needs to be done, and in which some very interesting results can probably be obtained with relative ease.

A special problem of demand analysis is the modal split of transport users between automobile and transit. The paper by Zupan discusses this and offers methods for predicting transit usage. The paper's main characteristic is that the prediction is done entirely on a theoretical basis using census data alone, and requires none of the costly and cumbersome field data collection procedures. It demonstrates the magnitude of undertaking such an analysis and the difficulty of identifying the basic parameters that underlie the choice of a transportation mode on an aggregate basis. I challenge each reader to give a precise analysis of his decision-process when he chooses between a car or transit. I guess that most of our urban commuters are ruled out because they do not even consider transit as a serious, possible alternative, but even the few who have the choice of using transit would probably be hard put to specify just what goes on in their minds when they choose transit over the automobile. This may be a good mental exercise for any transport planner the next time he has a choice.

The result of Zupan's work should become a major contribution not only in modal split forecasting itself, but more importantly in the ongoing quest to find simpler, cheaper, and yet more reliable methods for quantitative analysis of transport problems. In this respect, the paper represents an important example of a rather new approach to the theoretical understanding of transportation, and in particular, future transportation.

Moving on from software to hardware, we have a paper by Zworykin which deals with transit technology. Anyone who says that nothing new has been invented since the steel wheel on steel rail should take a good, hard look at this paper. It presents ideas about transit which might eliminate or reduce waiting times through the automation of transit operations on an exclusive right-of-way and under very stringent control conditions.

Zworykin, who is the co-inventor of television and an electronics expert, explains the need for highly improved transit service which stimulated him to attack this problem. He then proceeds to demonstrate that highly attractive systems with many innovative features can be designed. He proposes fully automated operation of individual cars, operating at minimum spacing or whenever there is demand by a patron. Cars would be stored on circular tracks under stations consisting of slowly revolving platforms which would provide continuous service and quick access. It would, of course, be possible to run these trains on conventional steel wheels on steel rails, or, as Zworykin proposes, on air cushions. Power for them might be provided by linear motors. This proposal, explained in detail in the paper, clearly demonstrates that there is ample room for imagination and innovation in mass transportation and that there are indeed other possibilities for mass transit than the present form of the rail system.

The paper by Heathington, Miller, Knox, Hoff, and Bruggeman entitled "Computer Simulation of a Demand-Scheduled Bus System Offering Door-to-Door Service" features the development of an algorithm for providing bus service from any particular point in a network to any other point. The simulation uses a process where simulated passengers call in and specify their origins and destinations. The computer then searches for a vehicle in the system which can service each particular call. It first analyzes whether the people already on a particular bus would be inconvenienced beyond tolerable limits if the call were serviced. If a bus is available and its change in routing is considered acceptable, it is sent to the caller. If it is not available, the next nearest bus is rerouted, and if no presently running buses are available, a new one is dispatched. This kind of operation can provide substantially improved service, particularly in low-density areas, for social trips, for trips between widely separated residential areas, for relatively infrequent shopping trips to smaller neighborhood centers, and even for trips into the downtown area from major terminals.

Not all is resolved in this simulation, however. More pages are devoted to what needs to be done than to what has been achieved so far. Another factor which is characteristic of this kind of simulation study is that as one attempts to resolve problems related to the development of this kind of transportation service, two new problems seem to arise for every one solved. In this case, the concept is basically relatively simple, but the execution presents serious problems. However, this is a concept in urban mass transportation that could be implemented almost immediately if we were willing to do some earnest thinking and experimenting. We could develop a progressively more sophisticated process with time, all the while improving transit services between the downtown and the relatively low-density suburban areas. In its convenience, this type of service would be second only to the automobile, and would certainly be a big improvement over conventional buses.

Two papers in this assortment deal with new concepts of individualized, public transportation, the suggested marriage of the advantages of auto and transit. Curiously enough, the titles of these two papers stress this marriage: "Small Car Automatic Transit" by Fichter and "Supra-Car" by Haikalis. They each deal with a transportation system for the city and are most profitably considered together. They utilize small individual cars on separate guideways whose control systems are fully automated. They provide not only what transit provides today, but also a flexibility which is very similar to that of the automobile.

Fitcher's system consists primarily of one-way elevated guideways with somewhat elaborate loops for switching from one main line to another. An interesting concept is the possibility of providing intersections at grade for those links whose capacities are relatively low. An analysis is given of expected capacities with single cars operating by themselves, single cars which could intersect at grades, and also several cars coupled together as single units. Fichter has given considerable thought to this particular concept, but it deserves still more as many questions still need answering: Are we going to direct our energies towards the problem of high capacity on the main links or are we aiming for a low-density distribution system at a reasonable cost? Are we thinking of individual vehicles or buses? Will we provide a pleasant visual experience for the occupant? Should we provide the possibility for individual routing that allows for a change of mind in midstream, or a system that immutably obeys one initial destination command? These are only a few of the questions which must be answered.

Haikalis has stressed another facet of the system by proposing a combination of vertical as well as horizontal service. In his system, capsules moving on an elevated guideway switch over to a vertical column and descend to the base of the column for loading and unloading of passengers. But why not make the columns into vertical elevators and extend the horizontal system into a vertical system? The system could be adapted to the movement of goods as well as people. If we had such an automated three dimensional access system, we might extend its capability to provide other kinds of services for houses and offices, e. g., water, sewage, and power.

Some intriguing numbers are manipulated by Haikalis. They are certainly very thought-provoking and should give readers some incentive for reflection on the future of transportation. Eight billion dollars are being spent every year by New Yorkers on urban transportation. With that huge sum an elaborate guideway system could be supported and could probably offer substantially better service than what now exists. Even while the calculations are very cursory, they clearly indicate once again that automated guideways are not an unrealistically expensive dream.

The remaining paper would seem to close the spectrum by addressing itself to the visual experience in transportation. Chermayeff, an architect with the firm of Cambridge Seven, did designing for Expo '67 and for some transportation facilities. His paper deals with visual orientation in a transit system, by identifying and structuring nonexistent or confusing information. At present, passengers who wish to transfer quickly and easily towards their destinations or to other transport modes remain disoriented, confused, and frustrated. Anyone who has tried to grope his way through an unfamiliar transit system will appreciate that this kind of problem exists almost everywhere. Ironically, many of the principles of good orientation and information can be applied with relative ease and at low cost. Perhaps they will begin to receive higher priority if their purpose, applicability, and implications can be better understood.

Chermayeff explains the various types of orientation that should be provided in the urban transportation system. First the system must be identified so people know it does exist and where to find it. Next, route information is needed, then station information, and finally vehicle direction. One must also be able to easily find connections throughout the system, and means for getting to them, not to mention a way to return to the outside world when the trip has been completed. Orientation is often in conflict with other information such as advertising. These conflicting types of information should also be recognized as such and treated accordingly.

This paper is significant in that it presents not only concepts, but actual results of designs that have actually been implemented in Boston. It opens the door, we hope, for much more substantive investigations into human reactions to the transportation systems and their information problems.

In conclusion, these papers give something of a state-of-the-art review of urban mass transportation. We probably cannot really expect very sudden major breakthroughs, but the good, hard engineering and analysis going into this problem may soon begin to provide some substantial improvements in urban mass transportation in the next few years.

Mode Choice: Implications for Planning

JEFFREY M. ZUPAN, Peat, Marwick, Livingston & Co.

To appraise land-use and transportation plans for the future, U.S. Census Journey-to-Work survey data were used to develop distribution and modal split models for work trips in the New York region.

Gravity distribution models were developed for each of three income groups. Using multiple regression techniques, an equation was derived that related walk-to-work trips to measures of a zone's self-containment. An equation to allocate work trips to transit and automobile modes was developed. It was found that the percent of transit trips for an origin-destination pair depends on employment density at the work end of the trip, residential density at the home end of the trip, availability of adequate rail service between origin and destination, relative times of the automobile and transit modes, the cost of tolls, and the cost of parking. Analyses of the root-mean-square error, geographical and transportation biases, and sensitivity to changes in the variables showed the equation to be a reasonable forecasting tool.

For each of three income levels, modal split equations were derived, including all of the same variables. Comparisons were made of the parameters of the three stratified equations and it was found that as the income level rose, the significance of transportation-related variables increased the significance of land-use variables decreased. Analyses of the stratified equations showed them to be reasonable forecasting tools. Examination was made of sensitivities for the assumption of a radically different distribution of income levels, and it was found that the sensitivities as well as predictive values would change appreciably. It was concluded that only if income level distribution were not changing radically would the unstratified equation be adequate for modal split forecasts.

The model calibration process required no trip data collection beyond that provided by the census survey. Future refinements have been suggested, particularly the use of a second point in time. Also, a recognition of the dynamic nature of the social structure is necessary to insure proper urban planning.

•AT a time when the entire structure of the urban environment is being reevaluated and large metropolitan areas are contemplating dramatic improvements in their mass transportation systems, rational means to forecast transportation demands are needed. Since it is the work trip that places the greatest burden on the transportation system, the characteristics of the work trip constitute a vital area of study for the transportation planner.

Paper sponsored by Committee on Future Concepts and presented at the 47th Annual Meeting.

To better evaluate transportation and land-use plans in the New York region, Peat, Marwick, Livingston & Co. (PML) developed a mathematical model for the Regional Plan Association (RPA). The model was designed to forecast work trips on an origin-destination (O-D) basis and to assign these trips to either the transit or the automobile mode. The source of trip data was the 1960 U. S. Census Bureau Journey-to-Work survey. The study area consisted of 31 counties in New York, New Jersey, and Connecticut, totaling 12,750 square miles. The area is inhabited by almost 20 million people, including 8 million workers.

The development of the distribution and modal split models represents a significant breakthrough in the transportation planning field in at least two respects. First, the trip data for model development were obtained from U. S. Census data only. Second, the model calibration process was completed using a system of large and relatively heterogeneous zones. In other words, a work trip model was calibrated without resorting to costly data collection procedures or complex zone systems.

A gravity distribution model was calibrated for each of three income levels. Using multiple regression techniques, we attempted to derive statistically significant relationships for walk-to-work trips and for work-at-home trips. No acceptable equations resulted for the work-at-home trips, but a sound equation was derived that related walk-to-work trips to an area's employment density and to its self-containment (the likelihood of finding employment within the worker's residential zone).

A modal split equation was developed that did not consider income as a mode choice determinant. The equation related the percent of transit work trips in an O-D pair to:

- employment density at the work end of the trip;
- residential density at the home end of the trip;
- availability of adequate rail service between origin and destination;
- relative times of the auto and transit trips;
- cost of tolls; and
- cost of parking.

The equation proved to be more than adequate when evaluated for the root-mean-square (RMS) error (the square root of the mean of the sums of the squares of the differences between the actual values of the dependent variable and those predicted by the equation), geographical and transportation biases, and sensitivity to changes in the values of the variables.

Modal split equations were also derived for each of three income levels. These equations included most of the variables cited. When the parameters of the three stratified equations were compared, we found that as income level rose, the significance of the transportation variables increased and the significance of the environmental or land-use variables decreased.

The RMS error, geographical and transportation biases, and sensitivity to changes in values of the variables were analyzed for the stratified equations. The stratified equations also proved to be good forecasting tools. Examining the modal split and the sensitivities of the variables to changes for a radically different distribution of income levels, we found that the sensitivities as well as the predicted values would change appreciably under such an assumption.

Therefore, if the purpose of the modal split forecast is to study the influence of transportation and land-use plans in the near future, the income-stratified modal split equations are unnecessary. However, if the purpose of the forecast is to study the influence of transportation and land-use plans for a time when income level distribution will be radically different, the income-stratified modal split equations should be applied to obtain a higher level of accuracy and proper sensitivities.

ABBREVIATIONS

CA = the cost of the automobile trip from origin to destination, including tolls, parking cost, and an over-the-road cost of 2.5 cents per mile (cents).

CT = the fare of the transit trip from origin to destination (cents).

D = over-the-road distance from origin to destination (miles).

ED = employment density (thousands of employees per developed square mile).
L = tolls from origin to destination (cents).
ln = natural logarithm.
N = number of data points.
P = parking costs at destination (cents).
R = coefficient of multiple correlation.
RD = residential density (thousands of residents in labor force per residential square mile).
SF = combined rail service factor for both no-transfer and one-transfer service.
S_N = rail service factor for no transfers.
S_T = service factor for one transfer.
TA = total travel time by automobile between origin and destination (minutes).
TT = total travel time by transit between origin and destination (minutes).
$\bar{y}$ = mean value of dependent variable.

THE MODEL AND IMPLICATIONS FOR THE FUTURE

Undoubtedly, the best way to develop a model to determine future mode choice is to simulate all factors that influence each traveler's decision. Much research remains to be done before we will be able to quantify all of these factors and forecast them. The model development described in this paper attempts to incorporate those characteristics of the trip and trip-maker that can be accurately and easily evaluated at the present time.

There are some limitations in the modal split model. The rail service factor is less than perfect because many levels of service are represented by identical values of this variable. The absence of a direct measure of transit cost could also be a serious problem. Our analysis showed that present transit fares do not significantly affect mode choice, but this might not be the case if new systems with radically different fares come into existence. The absence of a transit fare variable raises the question of whether we can properly evaluate exotic transportation systems of the future by applying a model based on the present transportation system. These limitations are the cause of legitimate concern, and investigation should be undertaken to remove them.

Perhaps the greatest criticism leveled at most transportation models is that they are based on one point in time. The assumption is usually made that the significant variables and the values of their parameters for the base year remain constant for future years. There can be no doubt that this assumption is open to serious question. To remove this objection, data sources for other years should be employed. If we can measure the changes in the significance of variables and in the size of the parameters over time, we could extrapolate these changes into the future. This approach could be attempted in the RPA region by using the data from the home interview survey that was taken by the Tri-State Transportation Commission in 1963. Another data source to consider will be the 1970 U.S. Census Bureau Journey-to-Work survey. Since transportation planning is a continuous process, it is vital that models incorporate new data as they become available.

Changes in the characteristics of the worker and the work trip may influence transportation planning in many ways. For instance, a growing number of married women are entering the nation's labor force. From 1940 to 1966, the rate of working wives under age 35 doubled, and the rate of working wives over 35 tripled (1). A second worker in the family may have a significant effect on mode choice. Since it is doubtful that a transportation planner in 1940 could have foreseen such a dramatic change in the nation's work characteristics, can we place much faith in our abilities to anticipate such changes?

The length of the work week is another factor that may influence model development. Thirty years ago a 6-day work week was in effect. The decline in the economic viability of our public transportation systems can be traced in part to the present reduction to a 5-day work week. We can expect that a possible further reduction to four or three days might further hamper the service and thus the attractiveness of public transportation. The shorter work week may also make the worker more tolerant of longer trips and less comfortable service, since the trip is made less frequently. Adopting a system of staggered working hours might have a major effect on mode selection, with the trip-maker reacting to changing congestion conditions. Increasing numbers of people in higher education programs for longer periods, coupled with earlier retirements, will serve to significantly alter the age distribution of workers. These factors may, in turn, alter their travel habits. A continued increase in the proportion of white-collar jobs also requires careful examination by the model-builder.

These are samples of changes in worker characteristics that must revise some of our basic assumptions in transportation planning.

The impact of far-reaching changes in the social order must not be overlooked. The application of new communication techniques and new energy sources and the ascendance of a semicomputerized society will have wide implications for planning. What might be the effect on society of changes in size, structure, or function of the family unit? And what will be the impact of full opportunity for the Negro in America? If heart disease and cancer are controlled, can we properly plan for the resulting changes in the age distribution of our population? Can we measure the values and ideals of an emerging class of leisure and affluence? In short, there are many complex ways in which a changing society can have implications for planning, and they are often difficult to identify and evaluate. It is clear that the planner must be aware of the dynamic nature of our social structure and he must relate this dynamism to his plans for society.

DISTRIBUTION MODEL STRUCTURE

The distribution process was accomplished by the gravity distribution model. That is, the total work trips produced in an origin zone, which are equal to the zone's resident labor force, were distributed to the various destination zones in proportion to the employment in each destination zone, and in proportion to an empirically derived friction factor that measures the propensity to travel between origin zones and destination zones. The definition of the gravity model distribution, stated mathematically is

$$T_{ij} = P_i \frac{A_j \cdot F_{(t_{ij})}}{\sum_{x=1}^{n} A_x \cdot F_{(t_{ix})}}$$

where

T_{ij} = trips produced in i that are attracted to j;
P_i = trips produced by i;
A_j = trips attracted by j; and
$F_{(t_{ij})}$ = empirically derived friction factor measuring propensity to travel between i and j.

The source of trip data was the U. S. Census Bureau Journey-to-Work survey, which is based on a relatively coarse-zone system (Fig. 1). For example, the entire Borough of Brooklyn was considered one zone. We used only census data, and the collection of additional trip data was not required to develop the model.

We attempted to calibrate the gravity model by the usual trial-and-error procedure of adjusting the friction factors, but the model could not be adequately calibrated. We decided to stratify the trip-makers by income level. We felt that if workers were separated by income at both residence and employment ends of their work trips, the gravity models would be able to match workers with jobs. Therefore, workers living in each zone and employees in each zone were separated into low-, medium-, and high-income groups, corresponding to annual incomes of $0 to $5,000, $5,000 to $10,000, and greater than $10,000.

Using the census data, the three gravity models were calibrated for the coarse-zone system. To determine whether the coarse-zone system reflected the distribution of

Figure 1. RPA study area coarse zones.

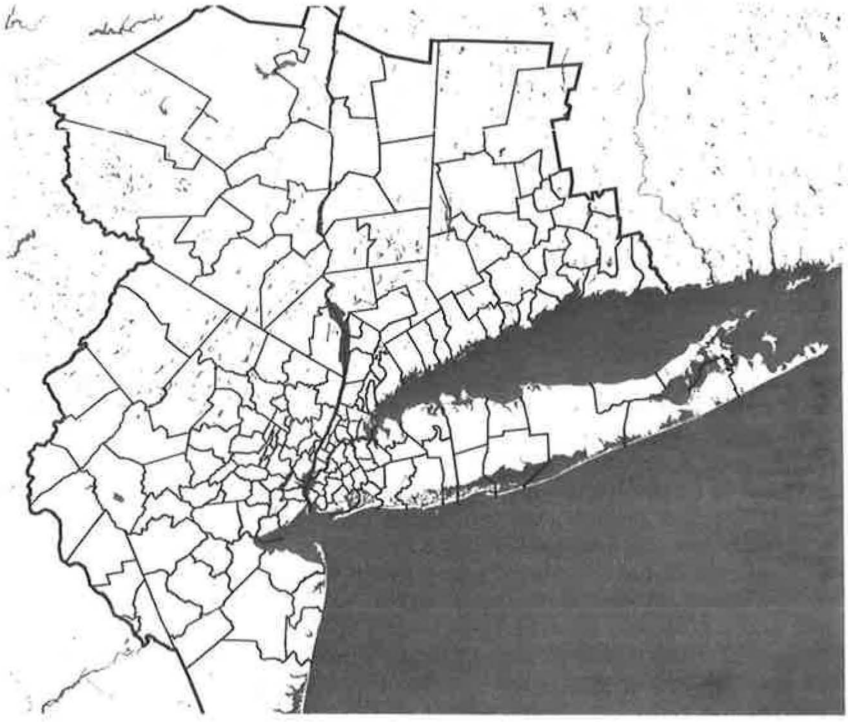

Figure 2. RPA study area fine zones.

work trips, the three gravity models were applied to a fine-zone system. (RPA has developed a 177-zone system, shown in Figure 2, which permits analysis of the region using relatively homogeneous zones.) The three resulting trip distributions were then compressed to the coarse-zone system for comparison with the source data. The two distributions agreed well, indicating that the gravity models were able to reproduce closely the zonal interchange trip volumes. The three sets of friction factors are shown in Figure 3.

MODAL SPLIT ANALYSIS

Since trip distribution required income stratification and since income level is intuitively relevant to mode choice, we decided to consider income stratification in developing the modal split model. The trip data used for the modal split analysis were taken from the 1960 Bureau of the Census survey of the Journey-to-Work. Data on the origin and destination of trips by mode, the number of trip-makers in each income group, and the number using automobiles or some other means of travel were available on the coarse-zone basis only.

Before developing the modal split equations, it was necessary to determine the number of people who did not use the transportation system, that is, those who either worked at home or walked to work. Data on income level were not available for these two categories. Since all other data were available for the fine-zone system, there was no ad-

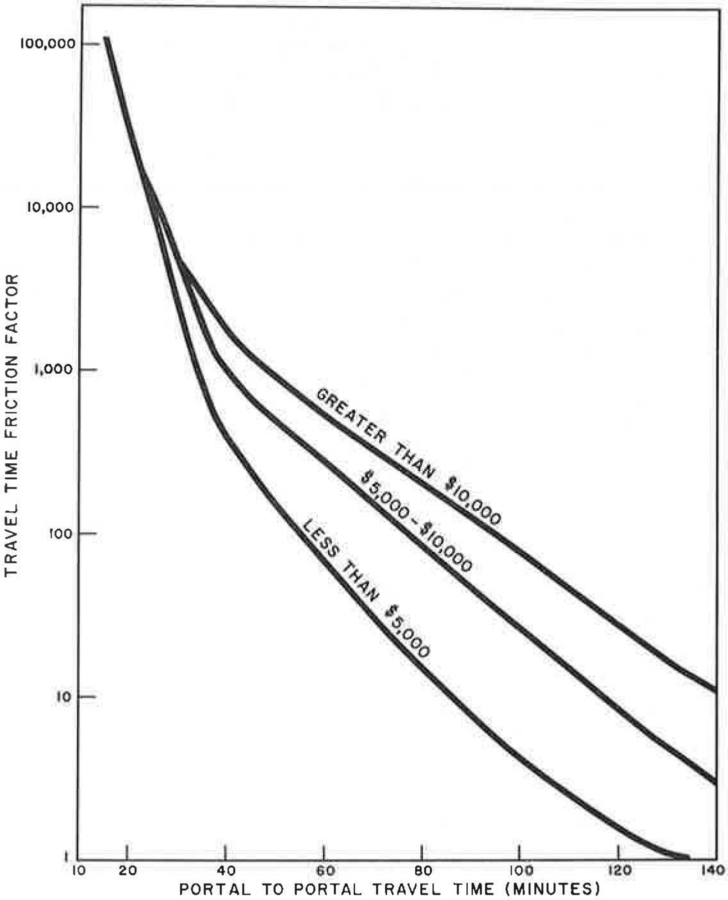

Figure 3. Gravity model propensity curves.

vantage to using the coarse-zone system for the walk-to-work and work-at-home analyses. Because the origin zone was of prime importance for these types of trips, the analysis was made by looking at the origin zones only. (For the person who works at home, origin and destination are identical; the destination of walk-to-work trips was identical to the origin, on the coarse-zone level, in 97 percent of the walk-to-work trips.)

Work-at-Home and Walk-to-Work Analysis

For regression analysis of work-at-home trips, the dependent variable used was the percent of the resident labor force that works at home. The independent variables were residential density (the resident labor force per net residential square mile) and employment density (number of employees per developed square mile). We felt that positive correlations would be found between densities and work-at-home percentages.

RPA calculated the values of residential and employment density. These values, as well as their natural logarithms and square roots, were tried in the regression analysis. The best results produced a correlation coefficient of 0.558 with a standard error of 2.67 percent. The mean value of the work-at-home trips was 3.75 percent with a standard deviation of 3.71 percent.

When we examined the residuals (the difference between the actual values and those predicted by the equation) of these results, we could find no additional variables that might explain the remaining variance. Apparently, many factors determine the portion of residential labor force that works at home. High percentages appeared in extremely high-income zones, where many professionals probably have offices in their homes; in agricultural zones, where farms serve as both home and place of employment; and in zones that have a large number of retail store owners who live on the store premises. Adding variables that reflected the peculiar zonal characteristics might have improved the results somewhat, but the net effect would have been minimal. We decided that none of the equations developed for work-at-home volumes was adequate for use as a forecasting tool. Therefore, we decided to assume that the work-at-home percentage remained constant for each zone, unless there were good reasons to assume otherwise for particular zones in future years.

Walk-to-work trips were also analyzed as a percent of the resident labor force. The independent variables were residential and employment densities and their natural logarithms. Next, a new independent variable, the percent of the resident labor force that made internal trips, was used. We thought that this variable, which measures a zone's self-containment, would reflect the likelihood of a worker's finding a job within walking distance of his home. Independent variables entering the equation, in the order of their significance, were employment density, percent internal trips of resident labor force, and the natural logarithm of employment density. This equation resulted:

$$WTW/RLF = 0.044\ ED + 8.349\ (INTRAS/RLF) + 0.907\ (\ln ED) + 4.109$$

where

WTW = walk-to-work trips,
ED = employees (thousands) per developed square mile,
$INTRAS$ = internal trips, and
RLF = resident labor force.

The correlation coefficient of this equation was 0.737 and the standard error was 3.72 percent. The standard deviation was 5.38 percent and the mean value of the dependent variable was 10.06 percent.

Development of Modal Split Equations

Next we focused attention on the trips that place a burden on the transportation system, i.e., automobile and transit trips. We decided to develop the modal split by devising relationships both for work trips unstratified by income level and for work trips stratified by the three income levels.

Before developing an unstratified modal split equation, we examined the income-stratified modal split, without using variables that measure characteristics of the auto or transit systems, in order to determine to what extent mode choice could be explained by residential and employment densities. If these variables explained mode choice completely, the implication would be that modal split would be affected only by the degree to which the transportation system could affect densities. The residential and employment densities and various transformations of them were used as independent variables for each of three income groups. Only O-D pairs where transit trips occurred were considered. Correlation coefficients ranged from 0.540 to 0.605 for the three groups. While these results were not suitable for use as forecasting equations, it was interesting to note the large amount of variance in modal split that can be explained without giving direct consideration to the characteristics of the transportation system.

Development of the Unstratified Modal Split Equation-Next, we developed an unstratified equation that included transportation system variables. Table 1 gives the regression results for these trials. The analysis contained 629 O-D pairs. Many O-D pairs were not used because density data were lacking. O-D pairs were also excluded if the number of work trips was represented by fewer than ten interviews from the census survey. This was necessary because the relatively large sampling errors that resulted from a small number of interviews produced an unreliable split between modes. O-D pairs were also excluded if no transit trips occurred, since the large number of such zonal pairs would tend to distort the equation at the lower end of the percent transit scale.

RPA developed average zone-to-zone travel times by transit for the 629 zonal pairs. Automobile times were determined by skimming the minimum time path from the auto network and adding access and egress times to and from each centroid. Zone-to-zone transit costs were determined by examining the fare structure of railroads, buses, ferries, PATH (Port Authority Trans-Hudson system), and the New York City subway system.

The determination of average zone-to-zone auto costs was a more difficult problem. It was important to consider how the trip-maker perceives his costs; after all, this is

TABLE 1

MODAL SPLIT REGRESSION ANALYSIS—UNSTRATIFIED BY INCOME

Dependent Variable	Variables Attempted	Variables Entered	Standard Deviation	Standard Error	$\overline{Y}$	R
% Transit	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, CA/CT, TA/TT	ln ED, $\sqrt{RD}$, TA/TT, CA/CT, ED	0.2550	0.1452	0.3341	0.824
% Transit	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, CA/CT (TA/TT)^2	ln ED, $\sqrt{RD}$, (TA/TT)^2, CA/CT ED	0.2550	0.1457	0.3341	0.822
% Transit	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, CA/CT, TA/TT, D	$\sqrt{ED}$, $\sqrt{RD}$, TA/TT, CA/CT	0.2453	0.1445	0.3368	0.812
% Transit	RD, ED, $\sqrt{RD}$, ln RD, CA/CT, TA/TT, $\sqrt[3]{ED}$, D	$\sqrt[3]{ED}$, RD, TA/TT, CA/CT	0.2543	0.1445	0.3368	0.824
% Transit	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, CA/CT, TA/TT	$\sqrt{ED}$, $\sqrt{RD}$, TA/TT CA/CT	0.2543	0.1483	0.3368	0.814
% Transit	$\sqrt{RD}$, ln ED, TA/TT, L + P	ln ED, $\sqrt{RD}$ TA/TT, L + P	0.2544	0.1430	0.3363	0.828
% Transit	$\sqrt{RD}$, ln ED (L + P)/CT, TA/TT	ln ED, $\sqrt{RD}$, TA/TT, (L + P)/CT	0.2544	0.1441	0.3363	0.825
% Transit	$\sqrt{RD}$, ln ED, L + P, TA/TT, S_T, S_N	ln ED, $\sqrt{RD}$, TA/TT, S_T, S_N, L + P	0.2543	0.1330	0.3360	0.854
% Transit	ln RD, ln ED, L + P, TA/TT, S_T, S_N	ln ED, ln RD, TA/TT, L + P	0.2543	0.1350	0.3360	0.849
% Transit	$\sqrt{RD}$, ln ED, L + P TA/TT, SF	ln ED, $\sqrt{RD}$, SF TA/TT, L + P	0.2543	0.1256	0.3360	0.871

his basis for choosing the way he will travel. For example, if the trip-maker does not view automobile depreciation as a commuting cost, it seems logical that the model-maker should not consider it. It seemed to us that the automobile costs that the commuter perceives are gasoline, oil, tolls, and average parking costs at his destination. Therefore, these costs were used in computing the cost variable. Gasoline and oil costs were assumed to be 2.5 cents per mile.

It should be recognized that these transportation system characteristics represent an "averaging" effect. Zone-to-zone travel times and costs reflect only an approximation to the actual times and costs experienced by all the trip-makers between residence and job.

Only variables that can be supported by intuitively sound arguments can be used in any regression analysis. It makes little sense to throw all possible variables into the pot in a shotgun approach merely to obtain high correlation coefficients. The unstratified modal split analysis considered the two density variables, their square roots and natural logarithms, the ratio of auto costs to transit cost, and the ratio of auto time to transit time. The density variables measure the trip-maker's environment at the home and work ends of his trip. A positive correlation of transit usage and density can be explained by assuming that higher densities will support more mass transportation service and increased service will attract greater usage. Time and cost ratios represent a comparison of two transportation system characteristics that are of major importance to the person choosing between alternate modes. Automobile ownership was not used as an independent variable because we felt that the high correlation it had with residential density would permit the density variable to serve in its place. Income, which is highly correlated with automobile ownership, was considered later for the stratified modal split model.

Use of the independent variables produced a regression equation with a correlation coefficient of 0.824. In the order of entry, the variables were natural logarithm of employment density, square root of residential density, time ratio, cost ratio, and employment density. Since we theorized that the effect of the time ratio would increase as the difference between the two times increased, the time ratio squared was tried in lieu of the time ratio in another trial; however, this trial produced no improvement in the results.

All the unstratified modal split equations developed to this point predicted internal Manhattan trips as over 100 percent transit. In an attempt to produce an equation that would predict transit usage for this O-D pair more realistically, we decided to bar the natural logarithm of employment density from the equation. This variable contributed most heavily to the high percent predicted for this particular interchange. Also, the square root and the cube root of employment density were tried instead of the natural logarithm, but the resulting equation predicted internal Manhattan transit trips no better than the previous one. We also tried the zone-to-zone distance of the O-D pairs to see if the length of the trip would affect the modal split. No significant correlation was found.

We therefore concluded that the time ratio and the natural logarithm of employment density were suitable to use for the modal split equation. However, we decided to examine the cost term further.

As mentioned earlier, it is the commuter's perception of cost that should be considered. Lansing and Hendricks (2) point out that less than one-third of automobile commuters actually compute their driving costs. Those that do compute the cost tend to overestimate the over-the-road cost per mile. This study also indicated that parking costs greatly affect the number of trip-makers using the automobile. Therefore, we decided to consider only tolls and parking costs as perceived auto costs, and to use the ratio of the sum of tolls and parking to transit costs as the variable. The sum of tolls and parking was also used directly, without relation to transit costs. When taken with the previously accepted variables, the best cost variable proved to be the sum of tolls and parking.

Analysis of residuals produced by this equation showed clearly that those zone-to-zone O-D pairs in which transit ridership was being underpredicted almost invariably had good rapid transit rail service. Two new variables were incorporated in the analysis to reflect this: a no-transfer rail service factor and a one-transfer rail service factor. If an O-D pair possessed rail transit service that allowed the trip-maker to travel without transferring, that O-D pair was rated as 1 for the no-transfer factor. Other O-D pairs received a 0. If the O-D pair possessed one-transfer service, it was rated a 1 for the one-transfer factor, the other O-D pairs received a 0. These two variables were tried with the four variables already determined. A correlation coefficient of 0.854 resulted; however, both rail service factors entered with approximately the same coefficients and significance. This indicated that one-transfer service did not have a significantly different effect on transit usage from no-transfer service. Accordingly, the two variables were combined and the analysis was performed again. The new result showed a correlation coefficient of 0.871 and a standard error of 12.56 percent. The mean value of the dependent variable was 33.6 percent with a standard deviation of 25.43 percent. The final unstratified modal split equation was:

$$\begin{aligned}\%\ \text{TRANSIT} &= 7.756\,(\ln ED) + 2.723\sqrt{RD} + 17.884SF \\ &\quad + 20.474\,(TA/TT) + 0.112\,(L+P) - 14.50\end{aligned}$$

where

ED = employees (thousands) per developed square mile at destination zone;
RD = resident workers (thousands) per net residential square mile at origin zone;
SF = rail service factor;
TA = zone-to-zone time by auto, in minutes;
TT = zone-to-zone time by transit, in minutes;
L = zone-to-zone toll cost, in cents; and
P = parking cost at destination, in cents.

These variables entered in the order given in the equation. Table 2 shows the statistical characteristics of the variables.

Analysis of the Unstratified Modal Split Equation—The root-mean-square error of the trips predicted by the unstratified modal split equation measures the predictive ability of the equation. Analyzing the residuals for particular geographic sectors or transportation systems determines whether geographic or transportation biases result from use of the equation. It is also necessary to test the sensitivity of the variables. Do reasonable changes in transit demand occur when one or more variables in the equation are altered?

For the RMS error analysis, the transit trips were computed using the predicted percent of transit, which was compared with the actual percent of transit usage. Since a few large, poorly predicted O-D pairs would distort the analysis, we focused attention on them. We discovered two major O-D pairs, Manhattan-to-Manhattan and Bronx-to-Manhattan, that would require special treatment.

As mentioned previously, the predicted percent of Manhattan-to-Manhattan transit usage was well over 100 percent, which is obviously impossible. What caused this poor prediction? The values of density and parking cost variables used in the modal split equation for this O-D pair weigh heavily against any auto usage. However, the equation is not sensitive to those trip-makers who must use their cars during the working day,

TABLE 2

STATISTICAL CHARACTERISTICS OF THE VARIABLES—UNSTRATIFIED MODAL SPLIT EQUATION

Variable	F-level Entering	t-Value Entering	Final Coefficient	Standard Error of Coefficient	Final t-Value
ln ED	492.2	22.2	7.756	0.445	17.4
$\sqrt{RD}$	298.5	17.3	2.723	0.169	16.1
SF	190.4	13.8	17.844	1.310	13.6
TA/TT	75.5	8.7	20.474	2.723	7.5
L + P	44.2	6.6	0.112	0.017	6.6

Note: The complete list of all regression trials is given in Table 1.

regardless of densities or costs, or those trip-makers who are rich enough to be unaffected by high costs. In other words, if the variables used were truly the only ones to be considered, absolutely no one would use an automobile for Manhattan-to-Manhattan work trips. We decided to eliminate this O-D pair from the RMS error analysis. The Bronx-to-Manhattan O-D pair also showed an impossibly high percent transit prediction. Here again, the value (99.9 percent) did not reflect trip-makers who must use their cars during the working day. This O-D pair was also removed from the RMS error analysis.

With these two data points omitted, the RMS error was 30.1 trips. This number can be interpreted as follows: the predicted volume of transit trips between any origin and destination is in error by less than 30.1 trips in 68.3 percent (one standard deviation) of the cases. It is in error by less than 60.2 trips in 95 percent of the cases and by less than 90.3 trips in 99 percent of the cases.

Next, we checked the predicted transit usage for various travel corridors. Table 3 gives the results. Because of the coarse-zone structure, the base used to evaluate the percent errors did not necessarily correspond to the actual volumes experienced in the corridors under study. For example, to calculate the percent error for the Erie-Lackawanna Railroad, a base of 22,300 trips was used instead of the 35,000 trips that actually occur, since only certain O-D pairs could be definitely identified as prime Erie-Lackawanna territory. For the geographic and transportation corridors analyzed, the ability of the unstratified modal split equation to predict transit trips appears to be excellent. The predictions for two important categories, "All transit trips to Manhattan" and "Subway trips in New York City," are particularly good.

Of course, the ability to reproduce only the past or present is not of any particular value. Since it is impossible to confirm the model's forecast of the future now, the best the analyst can do is examine the equation for reasonableness. Valid use of the modal split equation depends on its sensitivity to changes in the variables. Therefore, we examined the change in the dependent variable when the independent variables were allowed to vary.

Table 4 gives the changes in transit usage that will occur for five typical O-D cases. Case 1, travel from a high-density urban zone to the central business district (CBD), illustrates the change in transit usage for six variations:

- Ten minutes was added to auto time to simulate increased congestion on the highways into Manhattan; transit usage would increase from 91.6 percent to 95.4 percent, according to the model.
- Transit time was reduced by 10 min to simulate a widespread improvement in subway service; transit usage would increase to 96.2 percent. This variation and the preceding one indicate the sensitivity to travel times when auto and transit are competitive.

TABLE 3

UNSTRATIFIED MODAL SPLIT BIAS ANALYSIS

Category	Error of Predicted Transit Trips	% Error
All transit trips to Manhattan	+ 654	+ 0.07
All transit trips to Brooklyn	- 8,202	- 2.13
All transit trips to Queens	+15,889	+ 9.43
All transit trips to the Bronx	+ 7,714	+ 5.56
All transit trips to Newark	+ 8,339	+15.59
Bus trips to N. Y. C.—eastbound	+ 1,364	+ 2.31
Trans-Hudson transit trips—eastbound	- 2,280	- 1.64
Trans-Hudson transit trips—westbound	- 7,746	- 3.11
Subway trips in N. Y. C.	-13,236	- 0.67
New York Central R. R. trips to N. Y. C.	- 494	- 0.81
New Haven R. R. trips to N. Y. C.	- 1,539	- 9.17
Long Island R. R. trips to N. Y. C.	+10,951	- 9.41
Staten Island ferries to N. Y. C.	+ 4,554	+15.81
Pennsylvania R. R. to N. Y. C.—Mainline	+ 843	+ 4.22
PATH to N. Y. C.	- 963	- 4.59
Erie-Lackawanna R. R. to N. Y. C.	- 1,320	- 5.92
Central R. R. of N. Y. to N. Y. C.	- 297	- 2.54
Pennsylvania R. R. to N. Y. C.—Shore Branch	- 202	- 3.54

TABLE 4

SENSITIVITIES OF UNSTRATIFIED MODAL SPLIT EQUATION

CASE 1—HIGH DENSITY URBAN TO CBD (Brooklyn to Manhattan)

Present Values: ED = 230.860, RD = 55.553, TA = 50, TT = 52, SF = 1, L = 5, P = 50

Actual Transit Percent = 91.6
Predicted Transit Percent = 91.6

Variations	Δ%	New %
Add 10 minutes to TA	+ 4.0	95.6
Reduce TT by 10 minutes	+ 4.6	96.2
Double parking cost	+ 5.6	97.2
Provide free parking	- 5.6	86.0
Add 15 cents to tolls	+ 1.7	93.3
Provide free parking, halve employment density, and eliminate tolls	-11.6	80.0

CASE 2—SUBCENTER TO CBD (Trenton to Manhattan)

Present Values: ED = 230.800, RD = 2.127, TA = 100, TT = 99, SF = 1, L = 100, P = 50

Actual Transit Percent = 94.2
Predicted Transit Percent = 95.2

Variations	Δ%	New %
Double parking cost	+ 5.6	100.0+
Reduce TT by 15 minutes	+ 3.7	98.9
Double residential density	+ 1.9	97.1
Triple residential density	+ 3.0	98.2

CASE 3—SUBURBAN TO CBD (Suffolk to Manhattan)

Present Values: ED = 230.860, RD = 2.330, TA = 99, TT = 105, SF = 1, L = 9, P = 50

Actual Transit Percent = 74.6
Predicted Transit Percent = 75.6

Variations	Δ%	New %
Double parking cost	+ 5.6	81.2
Reduce TT by 25 minutes	+ 6.1	81.7
Double residential density	+ 1.7	77.3

CASE 4—SUBURBAN TO SUBCENTER (Milford to Bridgeport)

Present Values: ED = 3.904, RD = 3.164, TA = 19, TT = 39, SF = 0, L = 8, P = 7.5

Actual Transit Percent = 10.9
Predicted Transit Percent = 12.5

Variations	Δ%	New %
Triple parking cost	+ 1.7	14.2
Double employment density	+ 4.7	17.2
Reduce TT by 10 minutes	+ 3.4	15.9
Provide good rail service	+17.8	30.3
All 4	+27.6	40.1

CASE 5—SUBURBAN TO SUBURBAN (Western Essex Co. to Morris Co.)

Present Values: ED = 1.465, RD = 4.267, TA = 28, TT = 54, SF = 0, L = 0, P = 0

Actual Transit Percent = 4.3
Predicted Transit Percent = 4.7

Variations	Δ%	New %
Double residential density	+ 1.7	6.4
Double employment density	+ 5.3	10.0

- Parking costs were alternately doubled and eliminated, and this caused a variation of 5.6 percent in each direction, illustrating the model's sensitivity to this variable.
- A $0.15 toll increase, simulating imposition of tolls on free East River crossings, was tried. This produced only a slight gain in the proportion of transit users.
- A combination of changes was tested to simulate an emphasis on private automobiles. Free parking was introduced, tolls were removed, and employment density was halved to provide for increased parking. Auto travel times were held constant, on the assumption that the increased automobile trips will be handled by new facilities. The result was a drop in transit usage from 91.6 percent to 80.0 percent. Auto trips would increase by 240 percent, from 8.4 percent to 20.0 percent of the total.

Other cases examined included travel from a subcenter to the CBD and from a suburban zone to the CBD. Of current interest is the anticipated 100-mph commuter train. The model shows that the accompanying 25-min improvement in transit time from a suburban zone would reduce auto usage by 25 percent.

Case 4, suburban zone to subcenter, was particularly important since an accurate forecast of transit usage into the subcenters would be of great value in evaluating the concept of satellite cities. To test the sensitivities in this O-D pair, we tripled parking costs, doubled employment density, improved transit time by 10 min and provided rapid rail transit service. These combined variations increased transit usage from 12.5 to 40.1 percent of all work trips.

The final case tested, suburban zone to suburban zone, showed very little increase of transit usage when densities were increased. This is not surprising for such interchanges.

Although we cannot be certain that the variations examined will produce the calculated reactions, the sensitivities of the equation do seem to be intuitively reasonable.

Modal Split Stratified by Income—We next developed equations for each of the three income groups ($0 to $5,000, $5,000 to $10,000, and greater than $10,000 per year). Although the unstratified equation is quite adequate, we wanted to investigate the possibility of even finer results. This can be done by examining income-stratified modal split equations. When such equations were explored previously with no system variables, the results were promising.

Low-Income Modal Split—For the low-income group, the same O-D pairs used for the unstratified equation were examined after those pairs with no low-income transit trips were eliminated. The regressions were run using the density and cost variations, the rail service factor, and the time ratio. Table 5 gives the results of these trials. The statistical results of the first four trials were not as good as they were for the unstratified equation. Since these results were based on a smaller number of trips, we felt that sampling errors resulted for a number of O-D pairs. Accordingly, as with the unstratified modal split analysis, O-D pairs were removed from consideration if their sample size was less than ten.

When the regressions were rerun, the cost ratio terms were omitted from the analysis, since they showed up poorly in the first four runs. This time, the resulting equation did not even include those cost terms that were tried. To examine the effect of the cost term in the equation, the F-level-to-enter[1] was lowered from 9.00 to 4.00 so that the toll and parking cost variable could enter. Parking alone was also tried as the cost term, but it never entered the equation. The only decision remaining was whether to accept the equation with the tolls and parking cost value. The t-value[2] was 2.2, indicating a considerable likelihood that the true coefficient was not the calculated one. While the statistical evidence for keeping the variable was not overwhelming,

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[1] The F-level is a statistical index that enables the analyst to determine the probability that only chance factors cause the improvement in correlation resulting from adding a variable. Lowering the F-level increases the probability that the improvement in correlation is caused by chance factors.

[2] The t-value is a standard that enables the analyst to determine the probability that the coefficient computed using the sample has a value close to the coefficient that would be computed if the entire universe were considered.

TABLE 5

MODAL SPLIT REGRESSION ANALYSIS

Trial No.	Variables Attempted	Variables Entered	Standard Deviation	Standard Error	$\bar{Y}$	R	N	F-level to enter
		(a) Low Income						
1	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, L + P SF, TA/TT	ln ED, $\sqrt{RD}$, SF TA/TT, L + P	0.2636	0.1511	0.4057	0.821	613	9.00
2	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, (L + P)/CT	ln ED, $\sqrt{RD}$, SF TA/TT, (L + P)/CT	0.2636	0.1529	0.4057	0.816	613	9.00
3	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT CA	ln ED, $\sqrt{RD}$, SF TA/TT, CA	0.2636	0.1509	0.4057	0.821	613	9.00
4	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$ ln RD, ln ED, TA/TT, CA/CT	ln ED, $\sqrt{RD}$, SF TA/TT, CA/CT	0.2636	0.1519	0.4057	0.819	613	9.00
5	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P, D, SF	ln ED, $\sqrt{RD}$, SF TA/TT	0.2602	0.1284	0.3876	0.871	557	9.00
6	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, CA, D, SF	ln ED, $\sqrt{RD}$, SF TA/TT	0.2602	0.1284	0.3876	0.871	557	9.00
7	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P, SF	ln ED, $\sqrt{RD}$, SF TA/TT, L + P	0.2602	0.1274	0.3876	0.873	557	4.00
8	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$ ln RD, ln ED, TA/TT, L, SF	ln ED, $\sqrt{RD}$, SF, TA/TT, -RD, $\sqrt{ED}$, -ED, ln ED removed	0.2602	0.1263	0.3876	0.876	557	4.00
		(b) Middle Income						
1	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P, SF	ln ED, SF, RD, L + P, TA/TT	0.2612	0.1161	0.2771	0.897	538	
2	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, CA, SF	ln ED, SF, RD, CA, TA/TT, $\sqrt{RD}$, RD removed	0.2612	0.1138	0.2771	0.901	538	
3	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, CA/CT, SF	ln ED, SF, RD, TA/TT, CA/CT	0.2612	0.1209	0.2771	0.888	538	
4	ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P, SF	ln ED, SF, $\sqrt{RD}$, L + P, TA/TT	0.2608	0.1124	0.2763	0.903	537	
5	ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P S_N, S_T	ln ED, RD, TA/TT, L + P, S_T, S_N	0.2608	0.1122	0.2763	0.904	537	
6	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, CA, SF	ln ED, SF, RD, CA, TA/TT, $\sqrt{RD}$, RD removed	0.2608	0.1108	0.2763	0.906	537	
7	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, CA, SF	ln ED, RD, TA/TT, SF, CA, $\sqrt{RD}$, RD removed	0.2608	0.1107	0.2763	0.907	537	
8	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT L + P	ln ED, RD, TA/TT, L + P, $\sqrt{RD}$	0.2608	1.1318	0.2763	0.864	537	
		(c) High Income						
1	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P, SF	$\sqrt{ED}$, L + P, TA/TT, SF, -ED	0.2892	0.1341	0.2867	0.888	286	
2	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P	$\sqrt{ED}$, L + P, TA/TT, ED, RD	0.2892	0.1368	0.2867	0.883	286	
3	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED TA/TT, CA, SF	$\sqrt{ED}$, CA, SF, TA/TT, RD	0.2892	0.1291	0.2867	0.897	286	
4	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, CA/CT, SF	$\sqrt{ED}$, TA/TT, SF, CA/CT	0.2892	0.1508	0.2867	0.855	286	
5	RD, $\sqrt{RD}$, ln RD, ln ED, TA/TT, L + P, SF	ln ED, L + P, TA/TT, SF	0.2892	0.1357	0.2877	0.885	285	
6	RD, ED, $\sqrt{RD}$, $\sqrt{ED}$, ln RD, ln ED, TA/TT, L + P, SF	$\sqrt{ED}$, L + P, TA/TT, SF	0.2892	0.1362	0.2877	0.884	285	
7	RD, $\sqrt{RD}$, ln RD, ln ED, TA/TT, L + P	ln ED, L + P, TA/TT, RD	0.2892	0.1391	0.2877	0.879	285	

some sensitivity to automobile costs in the low-income equation seemed desirable. Therefore, trial 7 was adopted, and the low-income modal split equation became:

$$\begin{aligned}\%\ \text{TRANSIT} &= 9.289\,(\ln \text{ED}) + 2.978\sqrt{\text{RD}} + 16.431\text{SF}\\ &\quad + 17.447\,(\text{TA/TT}) + 0.043\,(\text{L} + \text{P}) - 8.997\end{aligned}$$

Table 6 gives the statistical characteristics of the variables.

Middle-Income Modal Split—The trials for the modal split analysis of the middle-income group are also given in Table 5. As with the low-income group, O-D pairs were removed when the census survey showed no transit trip-makers or when the total number of trips were represented by fewer than ten interviews.

Essentially the same variables that were tried for the unstratified and low-income analyses were tried with the middle-income analysis. Each of three cost variables was alternately tried with the density, time, and rail service factor variables. Trial 4 was selected even though trials 5 through 7 gave slightly better statistical results. We rejected these trials because the marginal improvement afforded by including over-the-road costs and two rail service factors would not warrant the added labor of determining their values for forecast years. Furthermore, using two service factors presented the additional difficulty of defining them and distinguishing between them for a future system. Consequently, this equation was selected for the middle-income modal split:

$$\begin{aligned}\%\ \text{TRANSIT} &= 7.251\,(\ln \text{ED}) + 20.572\text{SF} + 2.067\sqrt{\text{RD}}\\ &\quad + 0.167\,(\text{L} + \text{P}) + 21.875\,(\text{TA/TT}) - 19.584\end{aligned}$$

Table 6 gives the statistical characteristics of the variables.

High-Income Modal Split—The high-income modal split equation was developed in the same way as the low- and middle-income equations (Table 5). Trial 5 was preferred over trial 3 for the same reasons mentioned in discussing the middle-income equation. The high-income modal split equation was:

$$\begin{aligned}\%\ \text{TRANSIT} &= 7.010\,(\ln \text{ED}) + 0.307\,(\text{L} + \text{P}) + 25.840\,(\text{TA/TT})\\ &\quad + 11.399\text{SF} - 20.413\end{aligned}$$

Note that no residential density term appears in this equation. Table 6 gives the statistical characteristics of the equation variables.

Comparisons of the Income-Stratified Equations—To understand mode choice, it is useful to compare the three income-stratified equations. The crucial question is

TABLE 6

STATISTICAL CHARACTERISTICS OF THE VARIABLES

Variable	F-level Entering	t-Value Entering	Final Coefficient	Standard Error of Coefficient	Final t-Value
(a) Low-Income Equation					
ln ED	556.8	23.6	9.289	0.511	18.1
RD	307.3	17.5	2.978	0.189	15.8
SF	137.8	11.7	16.431	1.476	11.1
TA/TT	40.0	6.3	17.447	2.948	5.9
L + P	4.8	2.2	0.043	0.020	2.2
(b) Middle-Income Equation					
ln ED	679.6	26.1	7.251	0.482	15.1
SF	229.3	15.1	20.572	1.452	14.1
RD	139.8	11.8	2.067	0.173	11.9
L + P	93.7	9.7	0.167	0.018	9.3
TA/TT	68.4	8.3	21.875	2.645	8.3
(c) High-Income Equation					
ln ED	495.6	22.3	7.010	0.826	8.5
L + P	76.5	8.7	0.307	0.032	9.6
TA/TT	57.7	7.6	25.840	3.988	6.5
SF	25.9	5.1	11.399	2.241	5.1

whether the comparative values of the variables' coefficients are reasonable when related to our intuitive understanding of the three income groups. Table 7 should be helpful in answering that question. For four out of five cases, a pattern is readily discernible. As the income level rises, the employment and residential density variables carry less weight and the time ratio and cost variables carry more weight. The service factor follows an erratic pattern, increasing in value from low- to middle-income level, but decreasing for the high-income level. The constant term of the equations drops as the income level rises.

What can we infer from these comparisons? Low-income groups are more susceptible to their environment; that is, the choice to travel to work by automobile or transit is determined most often by the variables that measure the characteristics of the home and work locations, and not by the characteristics of the transportation system between travel points. The relative insignificance of the cost term for the low-income group reflects the fact that the poor person rarely considers automobile costs, probably because he does not have access to an automobile. He is the "captive rider" of the transit system and usually locates his home and job accordingly, i. e., in high-density locations. The high-income person, on the other hand, is likely to have a choice—to be able to consider freely the merits of the alternate transportation modes; hence the great significance of the cost variable for the high-income individual. People in the middle-income group are a combination of captive and choice riders: less beholden to the environment than the low-income group, yet not as free as the high-income group to choose a mode. The values of the constant terms suggest that as income rises the likelihood of using transit declines.

The one inconsistency in Table 7 is the behavior of the rail service factor coefficient, which decreases from the middle- to the high-income group. This result contradicts the thesis that the higher the income is, the more significant are the transportation system characteristics. This inconsistency might be explained by the contrast between the New York City subway system and the commuter railroads. Both warrant service factors, but for very different service. The high-income individual is not likely to be greatly influenced by the service factor for O-D pairs served by the subway. The subway is probably less attractive than his automobile, while the commuter railroad is probably a satisfactory alternative to driving. People in the low- and middle-income groups are likely to find the subway cost more attractive than the high cost of owning and using a car to drive to work; hence the higher coefficients.

Therefore, the variations in relative parameter values for the three income-stratified equations appear to be adequately explained by sound intuitive reasoning.

The Stratified Equations Versus the Unstratified Equation

The stratified equations must pass the same tests that the unstratified equation passed: they must have a predictive ability as measured by the RMS error; they must not introduce geographic or transportation biases; and their sensitivity toward changes in the variables must be reasonable. These analyses can be used both to examine the validity of the equations and to compare the unstratified equation with the income-stratified equations.

TABLE 7

PARAMETER COMPARISONS OF
INCOME-STRATIFIED EQUATIONS

Parameter	Low		Middle		High	
	Coeff	Rank	Coeff	Rank	Coeff	Rank
ln ED	9.289	1	7.251	1	7.010	1
RD	2.978	2	2.067	3	—	—
SF	16.431	3	20.572	2	11.399	4
TA/TT	17.447	4	21.875	5	25.840	3
L + P	0.043	5	0.167	4	0.307	
the constant	-8.997		-19.584		-20.413	

The RMS error for the stratified equations is 29.7 trips. Since the unstratified equation has an RMS error of 30.1, the equations show a similar level of predictive ability.

Analysis of geographical and transportation bias for the stratified equations was carried out in the same manner as for the unstratified equation (Table 8). Stratified equations produced better results in 10 of the 18 trip categories examined, but the unstratified equation showed up better for the important categories, "All transit trips to Manhattan" and "Subway trips in New York City." Examination for biases showed that both the unstratified equation and the stratified equations produce reasonable results.

The third means of evaluating the validity of the stratified equations is to test their sensitivities to changes in the independent variables. There were really three separate but related analyses to be made. First, the sensitivities of the stratified equations were examined. Second, we compared the effect of changes in the variables for both the stratified equations and the unstratified equations, based on the present income level distribution. Third, a comparison was made of the effects of changes in the variables based on a radically different income level distribution.

Table 9 illustrates the sensitivities of the income-stratified equations to changes in the variables. Comparable data for the unstratified equation are reproduced from Table 6. Case 1 shows that changes favoring transit did not produce as great an increase in transit percent usage for the stratified equations as for the unstratified equation. This was because the low-income equation produced a transit percent usage of over 100 percent when the improvement was made, and this had to be adjusted back to less than 100 percent. The same phenomenon is seen in Case 2, where the transit usage increases that accompany a twofold increase in parking cost are not as great for the stratified set of equations. Cases 3, 4, and 5 illustrate that the sensitivities of the stratified equations are reasonable. The unstratified equation has similar sensitivities for these O-D pairs and the variety of variable changes, indicating that similar results would be obtained using either the stratified or unstratified equations when testing a proposed land-use and transportation plan.

However, similar results would not necessarily occur if there are sweeping changes in the distribution of income levels. The coefficients of the three income-stratified modal split equations vary significantly for each of the variables. Therefore, any major change in the income level distribution may affect the modal split results.

The Regional Plan Association (3) has forecast that for the metropolitan region the percent of households earning less than $5,000 (in 1960 dollars) will decrease from

TABLE 8

COMPARISON OF UNSTRATIFIED AND STRATIFIED MODAL SPLIT BIAS ANALYSIS

Category	Unstratified		Stratified	
	Error	% Error	Error	% Error
All transit trips to Manhattan	+ 654	+ 0.07	+ 9,460	+ 0.96
All transit trips to Brooklyn	- 8,202	- 2.13	- 4,479	- 1.16
All transit trips to Queens	+15,889	- 9.43	+14,352	+ 8.52
All transit trips to the Bronx	+ 7,714	+ 5.56	+ 9,347	+ 6.77
All transit trips to Newark	+ 8,339	+15.59	+ 9,664	+18.06
Bus trips to N. Y. C.—eastbound	+ 1,364	+ 2.31	+ 1,052	+ 1.78
Trans-Hudson transit trips—eastbound	- 2,280	- 1.64	- 1,564	- 1.08
Trans-Hudson transit trips—westbound	- 746	- 3.11	- 1,335	- 5.55
Subway trips in N. Y. C.	-13,236	- 0.67	-30,569	- 1.55
New York Central R. R. trips to N. Y. C.	- 494	- 0.81	- 1,191	- 1.96
New Haven R. R. trips to N. Y. C.	- 1,539	- 9.17	- 1,099	- 6.55
Long Island R. R. trips to N. Y. C.	+10,951	+ 9.41	+ 5,773	+ 4.96
Staten Island ferries to N. Y. C.	- 4,554	-15.81	- 4,168	-14.47
Pennsylvania R. R. to N. Y. C.—Mainline	+ 843	+ 4.22	+ 1,055	+ 5.28
PATH to N. Y. C.	- 963	- 4.59	- 607	- 2.89
Erie-Lackawanna R. R. to N. Y. C.	- 1,320	- 5.92	- 1,489	- 6.68
Central R. R. of N. Y. to N. Y. C.	- 297	- 2.54	- 276	- 2.36
Pennsylvania R. R. to N. Y. C.—Shore Branch	- 202	- 3.54	+ 120	+ 2.11

TABLE 9

SENSITIVITIES OF STRATIFIED AND UNSTRATIFIED MODAL SPLIT EQUATIONS

CASE 1—HIGH DENSITY URBAN TO CBD (Brooklyn to Manhattan)

Actual Percent Transit = 91.6
Predicted Percent Transit—Stratified = 94.5
Predicted Percent Transit—Unstratified = 91.6

Variations	Stratified		Unstratified	
	Δ%	New %	Δ%	New %
Add 10 minutes to TA	+ 1.5	96.0	+ 4.0	95.6
Reduce TT by 10 mintues	+ 1.6	96.1	+ 4.6	96.2
Double parking costs	+ 3.2	97.7	+ 5.6	97.2
Provide free parking	- 6.0	88.5	- 5.6	86.0
Add 15 cents to tolls	+ 0.8	95.3	+ 1.7	93.3
Provide free parking, halve employment densities, and eliminate tolls	-10.7	83.8	-11.6	80.0

CASE 2—SUBCENTER TO CBD (Trenton to Manhattan)

Actual Percent Transit = 94.2
Predicted Percent Transit—Stratified = 95.7
Predicted Percent Transit—Unstratified = 95.2

Variations	Stratified		Unstratified	
	Δ%	New %	Δ%	New %
Double parking cost	+ 2.3	98.0	+ 5.6	100.0
Reduce TT by 15 minutes	+ 3.3	99.0	+ 3.7	98.9
Double residential density	+ 1.3	97.0	+ 1.9	97.1
Triple residential density	+ 2.3	98.0	+ 3.0	98.2

CASE 3—SUBURBAN TO CBD (Suffolk to Manhattan)

Actual Percent Transit = 74.6
Predicted Percent Transit—Stratified = 75.6
Predicted Percent Transit—Unstratified = 75.7

Variations	Stratified		Unstratified	
	Δ%	New %	Δ%	New %
Double parking cost	+ 8.1	83.8	+ 5.6	81.2
Reduce TT by 25 minutes	+ 6.1	81.8	+ 6.1	81.7
Double residential density	+ 0.8	76.5	+ 1.7	77.3

CASE 4—SUBURBAN TO SUBCENTER (Milford to Bridgeport)

Actual Percent Transit = 10.9
Predicted Percent Transit—Stratified = 11.6
Predicted Percent Transit—Unstratified = 12.5

Variations	Stratified		Unstratified	
	Δ%	New %	Δ%	New %
Triple parking cost	+ 1.4	13.0	+ 1.7	14.2
Double employment density	+ 5.4	17.0	+ 4.7	17.2
Reduce TT by 10 minutes	+ 3.2	14.8	+ 3.4	15.9
Provide good rail service	+17.7	29.3	+17.8	30.3
All 4	+27.7	39.3	+27.6	40.1

CASE 5—SUBURBAN TO SUBURBAN (Western Essex Co. to Morris Co.)

Actual Percent Transit = 4.3
Predicted Percent Transit—Stratified = 4.4
Predicted Percent Transit—Unstratified = 4.7

Variations	Stratified		Unstratified	
	Δ%	New %	Δ%	New %
Double residential density	+ 1.3	5.7	+ 1.7	6.4
Double employment density	+ 4.4	8.8	+ 5.3	10.0

TABLE 10

SENSITIVITIES OF STRATIFIED MODAL SPLIT EQUATIONS FOR PRESENT AND FUTURE INCOME LEVEL DISTRIBUTIONS

CASE 1—HIGH DENSITY URBAN TO CBD (Brooklyn to Manhattan)

Actual Percent Transit = 91.6
Predicted Percent Transit—Stratified—Present = 94.5
Predicted Percent Transit—Stratified—Future = 83.9

	Present Income Distribution (Low = 63, Mid = 32, High = 5)		Future Income Distribution (Low = 20, Mid = 50, High = 30)	
Variation	Δ%	New %	Δ%	New %
Add 10 minutes to TA	+ 1.5	96.0	+ 4.4	88.3
Reduce TT by 10 minutes	+ 1.6	96.1	+ 4.8	88.7
Double parking costs	+ 3.2	97.7	+ 9.2	93.1
Provide free parking	- 6.0	88.5	- 8.9	75.0
Add 15 cents to tolls	+ 0.8	95.3	+ 3.1	87.0
Provide free parking, halve employment density, and eliminate tolls	-10.7	83.8	-14.4	69.5

CASE 2—URBAN TO CBD (Trenton to Manhattan)

Actual Percent Transit = 94.2
Predicted Percent Transit—Stratified—Present = 94.5
Predicted Percent Transit—Stratified—Future = 97.8

	Present Income Distribution (Low = 45, Mid = 46, High = 9)		Future Income Distribution (Low = 10, Mid = 40, High = 50)	
Variation	Δ%	New %	Δ%	New %
Double parking cost	+ 2.3	98.0	+ 1.8	99.6
Reduce TT by 15 minutes	+ 3.3	99.0	+ 2.0	99.8
Double residential density	+ 1.3	97.0	+ 0.7	98.5
Triple residential density	+ 2.3	98.0	+ 1.2	99.0

CASE 3—SUBURBAN TO CBD (Suffolk to Manhattan)

Actual Percent Transit = 74.6
Predicted Percent Transit—Stratified—Present = 75.6
Predicted Percent Transit—Stratified—Future = 72.4

	Present Income Distribution (Low = 24, Mid = 56, High = 20)		Future Income Distribution (Low = 5, Mid = 15, High = 80)	
Variation	Δ%	New %	Δ%	New %
Double parking cost	+ 8.1	83.8	+13.6	86.0
Reduce TT by 25 minutes	+ 6.1	81.8	+ 7.2	79.6
Double residential density	+ 0.8	76.5	+ 0.3	72.7

CASE 4—SUBURBAN TO SUBCENTER (Milford to Bridgeport)

Actual Percent Transit = 10.9
Predicted Percent Transit—Stratified—Present = 11.6
Predicted Percent Transit—Stratified—Future = 8.0

	Present Income Distribution (Low = 41, Mid = 51, High = 8)		Future Income Distribution (Low = 10, Mid = 50, High = 40)	
Variation	Δ%	New %	Δ%	New %
Triple parking cost	+ 1.4	13.0	+ 3.2	11.2
Double employment density	+ 5.4	17.0	+ 5.1	13.1
Reduce TT by 10 minutes	+ 3.2	14.8	+ 3.9	11.9
Provide good rail service	+17.7	29.3	+16.5	24.5
All 4	+27.7	39.3	+28.7	36.7

CASE 5—SUBURBAN TO SUBURBAN (Western Essex Co. to Morris Co.)

Actual Percent Transit = 4.3
Predicted Percent Transit—Stratified—Present = 4.4
Predicted Percent Transit—Stratified—Future = 1.1

	Present Income Distribution (Low = 42, Mid = 42, High = 16		Future Income Distribution (Low = 10, Mid = 30, High = 60)	
Variation	Δ%	New %	Δ%	New %
Double residential density	+ 1.3	5.7	+ 0.5	1.6
Double employment density	+ 4.4	8.8	+ 2.2	3.3

37.2 percent to 12.8 percent between 1960 and 2000, and that the percent of households earning more than $10,000 (in 1960 dollars) will increase from 19.8 percent to 71.3 percent in the same period. We therefore felt it was advisable to compare the modal split sensitivities for the present income level distribution with those for a hypothetical distribution having a greater percent of high-income individuals. All other variables were held constant for this analysis. Table 10 illustrates the comparison, using the five cases discussed previously.

For all five cases studied, the predicted percent transit usage for a hypothetical future income distribution was appreciably different from what it was for the present income distribution. It is obvious that a major shift of the population to higher income levels can alter the modal split.

Cases 3, 4, and 5 show that the projected higher income distribution reacts more strongly to cost changes than does the present income distribution. It is also apparent that changes in employment densities or residential densities produce a weaker reaction for the future income distribution. These results are not surprising in light of the previous comparisons of the coefficients. Cases 1 and 2 do not permit effective comparisons of the two income distributions because of the limit of 100 percent transit discussed earlier.

The population shift into higher income levels will show a strong tendency to alter the modal split in favor of the automobile. As the trip-maker acquires the ability to support more automobiles for his family, he will also have a freer choice between transit and automobile. He will no longer choose transit because he does not have an automobile available; he will choose it only if it truly is the preferable mode of travel. He will become increasingly sensitive to transportation system characteristics and less sensitive to the characteristics of his home and work locations.

Comparison of the RMS error and the geographical and transportation biases of the unstratified equation with the stratified equations produced no clear-cut choice between them. When the existing distribution of income levels was applied, the sensitivities of the variables to changes in their values showed that both unstratified and stratified equations produced reasonable results that were not dissimilar. However, when future income level distributions were applied using the stratified equations, significant differences occurred both in the forecast modal split and in the sensitivities of the changing variables to transportation system and land-use changes.

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Computer Simulation of a Demand-Scheduled Bus System Offering Door-to-Door Service

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BUSTOP is a simulation model developed for the CDC 3400 using FORTRAN and SPURT languages. The simulation program uses stochastic principles to simulate a demand-scheduled bus system. A passenger's origin and destination are generated from a uniform distribution, and no limit is placed upon the number of locations of origins or destination. Thus, a computer algorithm has been developed that will solve the "many-to-many" problem.

Although this simulation package uses some very simplified assumptions, it is felt that a good beginning has been made toward a useful tool for transportation planning. With some specific modifications in the program, this simulation package could be used to perform detailed sensitivity analysis on the use of a demand-scheduled bus system before any demonstration project is implemented.

Much of the discussion has been oriented toward the implementation of a demand-scheduled bus system to help cope with the transportation problem. New concepts in small bus operations may lead to increased demand for certain types of transit services. However, the cost of demonstration projects is quite high and the use of simulation techniques could provide considerable insight into the economic feasibility of initiating a demand-scheduled bus system.

•AS A result of the steady population growth in urban areas, a multitude of social, economic, and technical problems has arisen of which not the least is the "urban transportation problem." This problem, stemming from increased mileage in urban travel, has placed a severe strain on the transportation system of our cities. Furthermore, the trend of suburban, low-density development coupled with core-oriented cities will continue to exert pressure on the existing transportation system. Concerning the urban transportation situation, there is much debate about the balance among the various transportation modes. Consequently, somewhat dogmatic opinions are frequently reported in various writings. Sometimes overlooked, however, is the role that the urban bus systems play in providing transportation opportunities. In 1960, nearly 75 percent of all urban transit trips were made on urban buses (1). Although statistics of this sort may not reflect the complete urban transit picture (in Chicago, for example, while there are over twice as many trips by bus as by rail transit, fewer person-miles of travel are by bus), it is obvious that buses are an important element in the urban transportation system (2).

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Improvement in the operation of urban bus systems is presently receiving considerable attention as a result of progressive legislation at the national level. Two important measures are the 1962 Federal Aid Highway Act and the Urban Mass Transportation Act. The former stipulates that comprehensive transportation planning include estimates of future demand by persons and goods for all modes of transportation both public and private. This Act has stimulated important research in modal-split models, and, more recently, in submodal split models, i.e., a model to estimate the proportion of transit riders split between rail and surface (bus) facilities. The development of these models has led to investigations of the social and economical characteristics of transit patrons and how they might react to innovations in the transit field.

While the Highway Act is concerned primarily with the planning aspects of urban transit, the Urban Mass Transportation Act is primarily directed towards operational problems. Numerous projects through the country are being partially supported by grants. Many final reports are now becoming available for demonstration projects such as radial express bus routes and crosstown express buses, for example, the final report that evaluates a $5, 000, 000 experimental research and development project near Pittsburgh where prototypes of an automatically guided and controlled bus system were developed (3).

SMALL BUSES

A Need For Small Buses

Cutbacks in service by transit operators in the suburban area have resulted in an almost complete reliance on the automobile for transportation. Yet a demand for transit service still exists in the suburbs. This consists of (a) captive riders, i.e., persons who neither own nor drive an automobile nor have access to one, and (b) potential riders who would switch from automobile to transit if a suitable level of service were offered. However, low-density suburban development and a resulting low density of demand for transit make regular transit service, at best, a marginal operation.

Small buses offering door-to-door service on a demand-scheduled basis, i.e., scheduled to pick up the customer at his convenience, might prove to be a profitable complement to the automobile. A demand-scheduled bus DSB system could provide flexible, convenient, and comfortable transportation during the day and in the evenings as well. DSB's could facilitate and even encourage social trips that have origins and destinations off the fixed routes of regularly scheduled transit facilities. A side effect could be the reduction of congestion and parking problems.

Small Bus Simulation

Computer simulation of small bus operation in low-density suburban areas has been moderately successful, although somewhat limited in scope (4). The Genie system proposed by students of MIT operates on a demand-scheduled basis—routes and schedules are determined by a computer reviewing locations of buses in the field and the instantaneous state of the demand. The system is designed to serve trips between one point (such as the CBD or a large shopping center) and all surrounding zones. No programs were reported that investigated the feasibility of door-to-door bus service to both dispersed origins and destinations. This is the so-called "many-to-many" problem.

The level of service offered by the Genie system is similar to that of taxi service but with a reduced fare structure made possible by using multi-passenger vehicles. The schedule of each bus is updated at each stop where either a delivery or pickup of passengers is made. The bus then proceeds to its next scheduled destination. Preliminary costing of the system has been made and is reported for rush-hour traffic.

In Menlo Park, Calif., taxi-bus operation was simulated under actual field conditions with radio-dispatched cars, drivers, and dispatchers (5). Time of passenger call, origin, and destination were randomly generated and then transmitted by telephone to the radio dispatcher, who transmitted the information via radio to the taxi-bus driver. The driver through his knowledge of the Menlo Park area scheduled his pickups and deliveries in a manner which he thought was optimum. The driver then delivered or picked up his "passengers" with an allowance for boarding or exiting time.

Two levels of demand were tested in the Menlo Park simulation project: 10 and 20 calls per hour. Eighteen residential addresses and five commercial addresses were selected at random. Trips were then "made" between the residential and commercial addresses.

Computer simulation of small bus, door-to-door operation on a demand-scheduled basis, in conjunction with field tests of prototype vehicles and communication systems, would be a very meaningful research project and would provide answers to many questions concerning this type of bus operation. The continual feedback from field operations could result in almost continuous adjustment of the computer simulation and would permit continuous evaluation of the entire project.

CHARACTERISTICS OF SIMULATION

Transportation problems have become extremely complex and involved with a multitude of variables. Too often the transportation engineer is faced with a seemingly impossible study or evaluation to perform. There are many variables that affect any given stillation, and determining the relationships of all variables becomes a very formidable task. It is in these areas of great complexity that simulation techniques become valuable to the engineer. Often, simulation offers transportation engineers or planners a method of studying complex systems and determining the relative importance of their parts.

The term "to simulate" is very general and all encompassing to some authors and is very restrictive to others. Shubik (6) defines simulation as follows:

> A simulation of a system or an organism is the operation of a model or simulator which is a representative of the system or organism. The model is amenable to manipulations which would be impossible, too expensive, or impractical to perform on the entity it portrays. The operation of the model can be studied and, from it, properties concerning the behavior of the actual system or its subsystem can be inferred.

This is a very general and broad definition of simulation which could incorporate anything from a mathematical to a mechanical model. With Shubik's definition we can apply the term simulation to a soap-box racer, a model bridge, or a mathematical model. To be specific in defining simulation as it applies to this presentation, we use the following definition:

> Simulation is a numerical technique incorporating the use of random numbers, probability functions, and mathematical identities to form a stochastic model that can be used to perform a sensitivity analysis on any given or derived system over extended periods of time. The computational procedure is generally more easily performed with the aid of a computer.

In describing the simulation process, definitions of some of the more commonly used terms are useful.

Entities are the active or physical parts of the world which are simulated. Entities would include vehicles, passengers, roadways, traffic signals, messages, and any other describable object.

An exogenous variable is an input to the model. It is external to the system. As an example, the number and frequency of calls are used as exogenous inputs in this simulation process. However, an output from the model can be used as feedback to change the values of the exogenous variables once the simulation process has begun.

An endogenous variable is an internally generated variable. As an example, the pickup and delivery times for each passenger are endogenous variables.

Control parameters are those variables which can be kept constant or changed during the simulation process. As an example, the maximum number of buses to be assigned to the system can be allowed to remain at a constant number or be allowed to change with an increase in demand. These control parameters can be changed from one simulation run to another to permit sensitivity analyses to be made.

Identities are the mathematical relationships used within the model. As an example:

$$\text{Distance} = \text{ABSF}(\text{Xbus} - \text{Xcall}) + \text{ABSF}(\text{Ybus} - \text{Ycall})$$

where

Distance = distance from the origin of the call (where the passenger is to be picked up) to the bus;
Xbus = X coordinate of the bus;
Xcall = X coordinate of the call;
Ybus = Y coordinate of the bus;
Ycall = Y coordinate of the call; and
ABSF = the absolute value.

Outputs are results obtained from running the simulation model. They may simply be a list of the events and the accompanying times of occurrence or a solution to a question such as the number of buses required to serve a given demand. Statistical measures such as the distribution of waiting times for all passengers may also be outputs from the model.

Utilization of Stochastic Principles

Uncertainty characterizes some of the more important problems. Various probability distributions are used in simulation in order for the random numbers generated to be from a given type of population. As an example, the origin of a call in the simulation of a bus service was assumed to be from a uniform distribution. That is, any location within the designated service area had the same probability for being the origin of a call. The destinations were treated in a similar manner. The number of calls during a given time interval was also assumed to be from a uniform distribution.

One of the more attractive features of simulation is that the probability distribution can be changed to represent more closely the real world data. For instance, it might be known that the origin of a call might follow a distribution other than a uniform distribution. If this should be the case, the distribution more closely representing the true distribution could be substituted. The probability distribution for the number of calls for a given time interval might be more appropriately described by a Poisson distribution. Perhaps a distribution can be obtained from sampling that would more closely represent the population than any of the "standard" distributions. The important point is that any distribution can be used and can be changed or altered at any time to perform a more detailed sensitivity analysis. BUSTOP allows for the use of any desired probability distribution.

There are many ways to generate random numbers from various probability distributions. Naylor, et al, give detailed methodology for generating random numbers (7).

Validation

The validation of a computer simulation model is perhaps the most difficult part of simulation. In many simulations, it may well be impossible, impractical, or uneconomical to perform a complete validation. If historical data exist than the outputs from the model can be tested against the available data. However, too often data are not available.

To validate a bus simulation, current passenger demands (i.e., number of passengers picked up at each bus stop) from existing transit agencies could be used as inputs to the simulation model. The simulation outputs could be compared with any existing data from the transit agency. However, this does not insure a completely acceptable simulation model when it is applied to a different geographical area where the external variables are changed. A bus project could be put into operation to validate the model, but this, of course, is an expensive method. If a large number of variations are permitted in a real demonstration such as can be allowed in a simulation process, then the cost quickly becomes prohibitive.

Computer Languages

Many special purpose simulation languages are available for use. However, many of the languages cannot be used from one computer to another as FORTRAN can be used. Some of the special languages are GPSS, SIMSCRIPT, and DYNAMO. The language used in this simulation was SPURT which is a FORTRAN IV simulation language developed at Northwestern University for the CDC 3400 (8).

THE SIMULATION MODEL

BUSTOP has been specifically developed to simulate an urban-suburban DSB system, which required the general model to solve the so-called many-to-many problem; that is to say, that passengers can require pick-up or delivery at any of a large number of points.

Assumptions

In solving this problem, certain assumptions were made to simplify computation. All of these can be modified to permit the introduction of more generality into the model.

The most obvious assumption is the structuring of the street network. A model city has been drawn which is one mile by one mile. The streets are regularly spaced to provide a grid 9 blocks square. The streets are numbered 0-9 from west to east and from north to south. Thus, a pair of digits locates a particular intersection or node. The bus terminal is located at node (5, 5). All buses originate from this terminal and return there when empty. Bus capacity can be varied, but was normally held to equal 5.

All buses travel either east or west first before traveling north or south. The direction of travel can be determined by comparing the present position of a bus to the coordinates of its next destination. Buses pick up and discharge passengers only at intersections.

Model Input

To make the model as general as possible, a large number of the model's control parameters are left to the judgment of the programmer.

A list of calls for bus service is an exogenous input. Each call generated must include the time the call occurred, the originating node of the call, and the destination node. Each of these variables can be generated as stochastic variables. In the initial programming, the time of each call and the coordinates of the origin and destination were derived from uniform distributions.

Passenger service criteria were developed to insure a reasonable level of service. A minimum and maximum pickup time were specified. This guaranteed the passenger some time after he called the bus to reach the intersection for pickup and that he would be picked up before a maximum time limit had elapsed. These quantities were variables and initially were 1 and 6 minutes, respectively.

An additional criterion determined a maximum travel time. This was a linear function:

$$\begin{aligned}\text{Max Travel Time} &= kn \text{ for } n \leq n' \\ &= T + tn \text{ for } n > n'\end{aligned}$$

where

n = number of links between origin and destination (a link is one block long);
n' = a control parameter constant set equal to 10 links;
k = a control parameter constant which equals 1 min/link;

T = a control parameter constant which equals 5 min; and
t = a control parameter constant which equals $\frac{1}{2}$ min/link.

The variable t also represents the travel time assigned to each link. This travel time corresponds to a running speed of 13 mph. This criterion is felt to be one of the more sensitive parts of the model and can be easily revised to perform sensitivity analysis.

In addition, a time penalty was assigned to the bus for each pickup or delivery operation. This control parameter was initially set equal to 15 seconds.

Operation of the Model

The key to the operation of this simulation is the CLOCK subroutine of the SPURT simulation package. CLOCK causes events to happen at the proper time. As events are entered into CLOCK, they are ordered according to time of occurrence. An event number associated with each event time identified the type of action to take place. CLOCK also provides for storage of events which could not take place when scheduled. These events are assigned a queue position and will take place at the earliest possible moment in the program.

Each event is entered into CLOCK as an event type (designated by a number) and a scheduled time of occurrence. This list of events can be manipulated to permit loading various combinations of events into the list or purging then from it.

A general flow chart is shown in Figure 1. As an event is called from the CLOCK, the scheduled time of occurrence and the type of event is determined. All action pertaining to this event is completed before the next event is called. The BUSTOP simulation is comprised of three events: an incoming call demanding bus service, the arrival of a bus at a node, and the production of summary data.

Within the simulation, a number of lists are used to keep track of the model's activities. A passenger list (PLIST) is used to summarize the characteristics of each passenger's trip. PLIST includes the passenger's origin and destination, trip length, service criteria, times of pickup and delivery, and the number of the bus assigned to transport the passenger. A bus log records all activities performed by a given bus. All

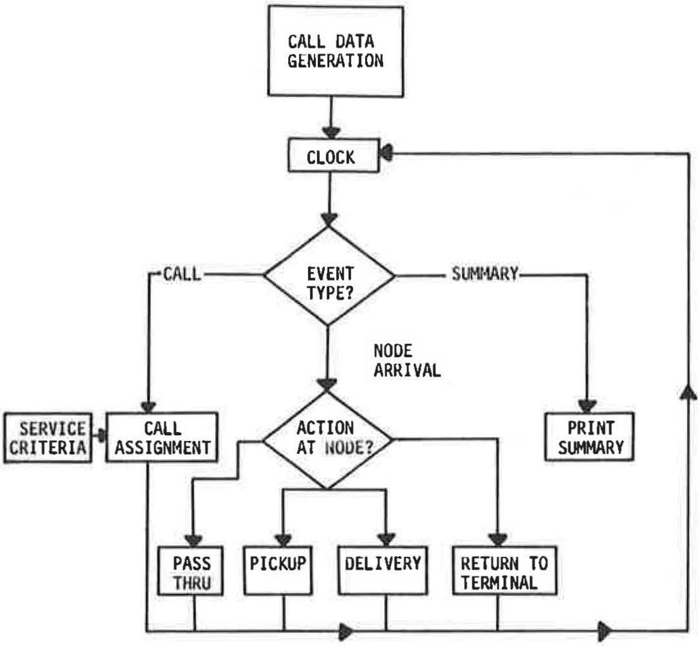

Figure 1. General flow chart.

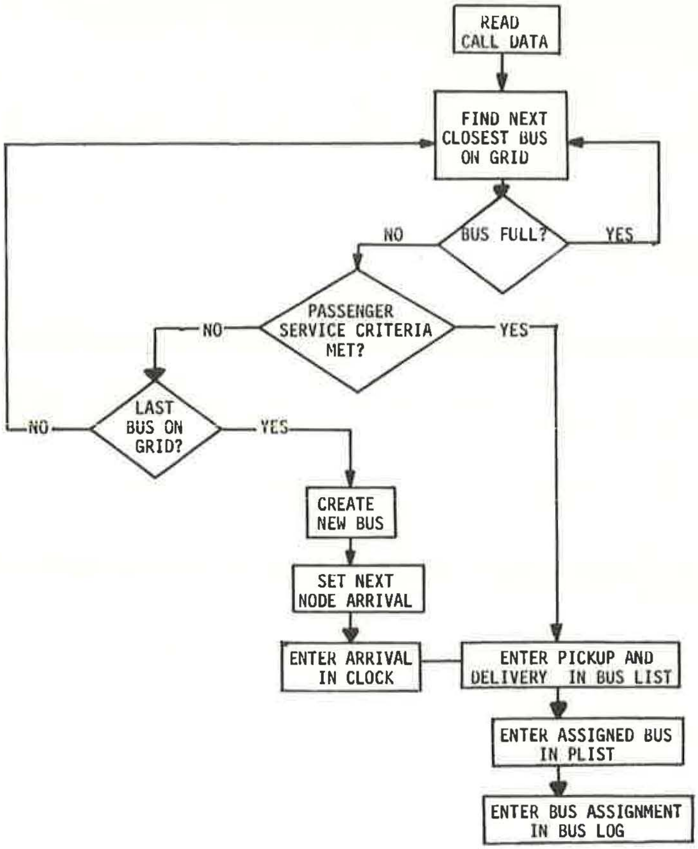

Figure 2. Call assignment.

passenger assignments, pickups, deliveries, and the return of a bus to the terminal are entered by each bus. A separate list for each bus allows testing to determine whether a specific call can be accommodated by that bus.

Call Assignment—If the event called from the CLOCK is a call or demand for service, a bus must be assigned to accommodate the call. The assignment process is outlined in Figure 2. The origin, destination, and occurrence time of the call are determined. The closest bus on the grid is examined to see if adding this passenger to those already assigned will violate capacity restrictions or will result in any passenger's service criteria not being met. If all passengers can be accommodated without violating the service criteria, necessary changes are made in the bookkeeping lists. A new event is then called from the CLOCK.

If the closest bus cannot meet the service or capacity criteria, the next closest bus is considered. If every bus on the grid is incapable of accommodating the new call, a new bus is dispatched from the terminal. The pickup and delivery data are then entered in the bookkeeping lists.

This call assignment is definitely not optimal. No attempt is made to assign a passenger to a bus so that efficiency of the system is maintained at an optimum. Once a passenger is assigned to a bus, that assignment is not changed, regardless of the actions of other buses in the system. The method of assignment is feasible and might reflect at least one algorithm which might be used in a demonstration project. Since the assignment method is a separate subroutine, modifications can be made to gain some insight into the sensitivity of system efficiency to changes in the call assignment method.

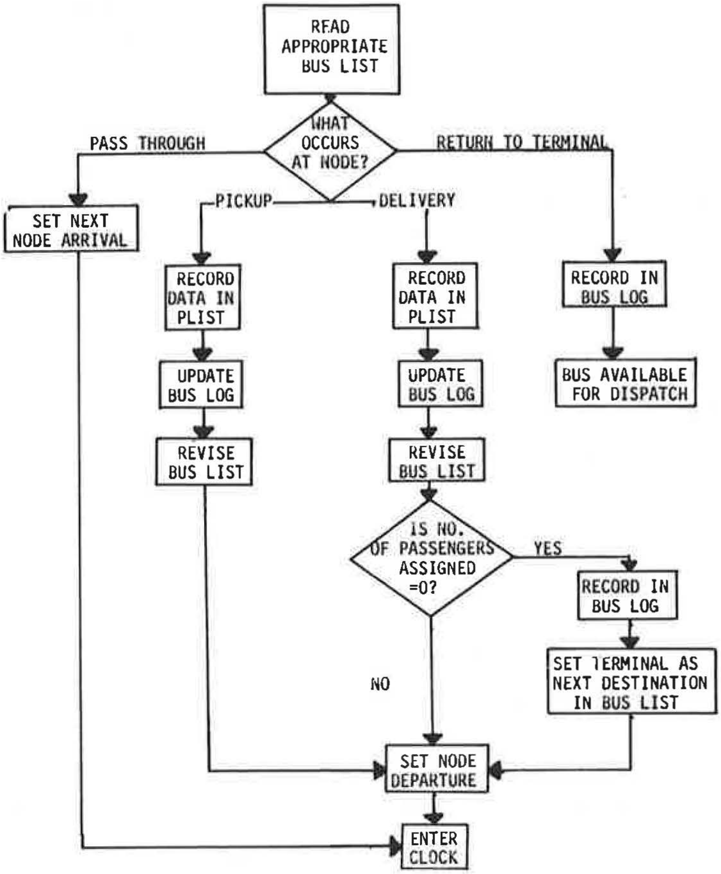

Figure 3. Action at node.

In early tests of BUSTOP, system efficiency was measured by characteristics of each passenger's trip. The mean times for a number of simulation runs that a passenger had to wait for pickup after placing a call ranged from 2.5 to 3 minutes. Excess time was the amount of time that a passenger spent on the bus above that which he would spend if he were the only passenger. Excess time is thus a measure of the delay caused by pickup and delivery of the other passengers. Mean excess time ranged from 3 to 4 minutes. Since no other call assignment algorithms were programmed, it is impossible to tell how these measurements might change. The means, however, do not seem to be unreasonable.

Events Occurring at a Node—If the event called from the CLOCK indicates that a particular bus has arrived at a node, the bus list for that bus is scanned to determine what action is to be taken (Fig. 3). If the bus makes no pickups or deliveries at that node or has not returned to the terminal, the coordinates of the next node are calculated and the time of arrival at the next node is determined and put into the CLOCK. The last entry in each bus list is a special entry indicating that the bus is empty, has no more assignments, and has returned to the terminal.

If the bus list indicates that a passenger is to be picked up at this node, the passenger is recorded as being picked up in the bookkeeping lists. A $\frac{1}{4}$-min pickup penalty is added to the current time and the time of departure from the node is entered into the CLOCK.

When a delivery is to be made at this node, the necessary entries are made in the bookkeeping lists. If the bus has no more passengers assigned to it, the coordinates of the terminal are set as the next destination of the bus. As with a pickup, a $\frac{1}{4}$-min penalty is assessed and the time of departure is placed in the CLOCK.

A bus which arrives at the terminal with no other actions assigned to it is retained there for future assignments.

Throughout the simulation process, variables are updated to allow analysis of the system operation.

Output of the Model—Initial trials with the model found the following descriptive statistics to be helpful in analysis.

1. Passenger Statistics
   a. Waiting time distribution: a measurement from the time the demand call is originated until the bus arrives to pick up each passenger.
   b. Travel time distribution: the time spent on board a bus by each passenger.
   c. Total time distribution: the time spent from origination of the demand call until delivery at the destination for each passenger.
   d. Excess time distribution: the amount of time spent on the bus in excess of the time required for minimum travel time between the origin and destination for each passenger. The sum of the excess time is also calculated.
2. Bus Statistics
   a. Roadtimes for buses: the amount of time which each bus has spent traveling on the roadway grid.
   b. Bus minutes distribution: the distribution of roadtimes.
   c. Passenger minutes distribution: the number of passenger minutes accrued for each bus.
   d. Percent time on road: the relative time each bus has spent on the road compared to total time since the bus was initially dispatched from the terminal.
   e. Passenger minutes per bus minute: a relative measure of the extent to which each bus achieves its capacity.

Additional outputs were utilized to increase insight into the detailed operation of the model. At selected CLOCK time intervals, a subroutine called SUMMARY caused certain of the entries in the bookkeeping lists to be printed. Bus log entries for all buses are printed according to time of occurrence. This yields a complete record of all transactions completed since the last time the summary subroutine was executed. Bus lists for selected buses are printed to allow inspection of uncompleted activities. The position of all buses at the time SUMMARY is executed is also printed.

FUTURE WORK ON THE MODEL

Further work is necessary to extend the initial BUSTOP model. This work has two purposes. The first is to develop a more realistic simulation model which would account for demands from an actual city. More realistic street patterns and travel times should be incorporated into the model. The second is to investigate the feasibility of the bus system. This investigation would consider costs, fares, and subsidies necessary to operate such a system, and how the system operating and service characteristics compare with other modes such as public transit, auto, and taxicabs (Fig. 4).

Demand

As it would be hard to estimate the initial and long-run demands for such a system, a range of reasonable values would be estimated. Analyses carried out for several levels of demand would help to establish the limits for economic feasibility. In addition, possible fare and subsidy relationships would be developed for each demand level tested.

The demand level would be expressed in calls per hour. Different call frequencies for origins and destinations would be assigned to different subareas of the study area. The range of call frequency would be determined from a heuristic analysis of land use, alternative transportation modes, socioeconomic information, number of cars per household, trip purposes, and captive public transit ridership. Service characteristics and fare structure would also be included.

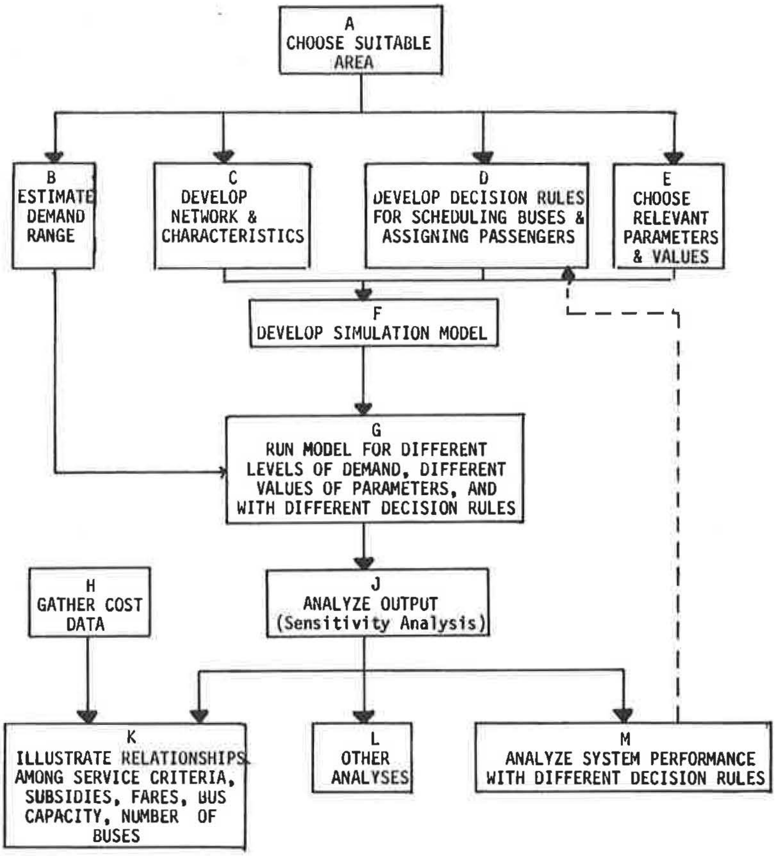

Figure 4. DSB simulation model development flow chart.

Service Criteria

To be realistic, the envisaged system would operate with a limited number of vehicles and chauffeurs. Thus, the absolute guarantees on pickup and total times used in the initial model could be violated in periods of peak demand. Whereas the initial model guaranteed that each passenger would be picked up within 5 minutes, the new model could possibly consider the distribution of pickup times. The system then would have an expected pickup time and would aim towards picking up, say, 95 percent of the passengers within 5 minutes. The expected and the 95 percentile pickup times would again be adjustable parameters in the model and system operation, and costs could be examined over ranges of these two parameters. The total time on the system would be treated in a similar manner. The expected total time would depend on the trip distance. It would be expressed as Kt, where t might be the auto travel time and K the same factor greater than 1. Existing transit travel time might also be used for t in which case K would be less than 1.

Network Structure

Since the study area for the new model would be considerably larger than the simple network in the initial model, a slightly different procedure would be employed. For the larger area it would probably not be feasible to include all streets and all intersections in the study area from a programming point of view. For the operation of the model this would not be necessary either. The links of the network would consist of major arterial and collector streets. In addition, groups of less important streets would be combined into single links.

The service provided would still be door-to-door. Each node would serve as intersections on the grid as well as origins and destinations of the trips. To account for the fact that not all trip ends are located exactly at the nodes, the pickup and delivery penalties would be replaced by an average "access" time, which would include time to travel from the node to the actual trip end, time for the passenger to enter or leave the vehicle, and time to return to the same node. Each node would have a different access time.

After the average travel times on each link are estimated, minimum time path trees could be generated to obtain the shortest travel time with the corresponding route between each pair of nodes.

Decision Rules—Scheduling and Routing

The decision rules assign passengers to the buses and set the order in which the passengers assigned to a given bus are to be served. The objective of these decision rules is to make the assigning and scheduling process as close to optimal as possible. One such set of decision rules has already been discussed. It is proposed that other sets be developed and tested to see which set enables the highest service levels and lowest operating cost. It may be that different sets be desired for peak and off-peak operation.

The assigning and scheduling would be done using average travel times via the quickest routes. A new algorithm has to be developed for routing the buses and keeping track of them. It is proposed that from the tree generations a "next-node" matrix be developed. The row subscripts of this matrix would be the current location of the bus. The column subscripts would represent the next node in the bus list. The entries would contain the identification number of the next node the vehicle must pass through on the shortest path to the next node on the bus list. When the vehicle reaches each point it looks at the matrix again to find the succeeding node. In this way, the location of the bus can be readily determined at all times.

Vehicle Movement

Whereas the bus schedules would be determined using the average link travel times, in reality the buses could not be expected to keep exactly to it. To simulate this, as the bus enters each link, its travel time on it could be stochastically determined from a distribution which uses the average travel time as a distribution parameter.

System Costs

For the feasibility analysis the costs to be considered would be those of vehicles, communication equipment, maintenance, repairs, operating personnel, and computer time.

Input Variables

For the model runs there would be four basic parameters which would be varied: (a) demand level, (b) level of service, (c) bus size, and (d) number of buses. For each combination of demand level and level of service, the combination of bus size and number of buses which yields the minimum total cost would be determined. From these combinations, relationships among total cost, demand, and service can be illustrated. The total cost can further be divided into fares and subsidies and more relationships shown.

In addition to varying the above four parameters, different decision rules can be tried out to see if better service can be provided and if the number or size of buses can be reduced.

Other Analyses

Other analyses would be carried out to provide additional information about system performance. For example, a fixed-route fixed-schedule system could be compared to the door-to-door service. A comparison could also be made of the cost and efficiency of using competent dispatchers in place of a computer.

DEVELOPING AN OPERATIONAL SYSTEM

The Vehicle

The size and type of vehicle would depend on the level of service desired, economic considerations, and handling characteristics. It would most likely be designed to carry from 4 to 20 passengers. It would require good acceleration characteristics because of the frequent stops and the ability to maintain speeds commensurate with the speed limits of the area.

For the type of service studied in the initial simulation runs, a small compact vehicle, carrying 4 to 7 passengers, would be most practical. It would be easy to handle on local streets, and it would not have an adverse effect on the environment or on other vehicles.

Larger vehicles might be more economical if a different type of service (solely on arterial streets, for example) were to be provided or if the trip patterns were strongly oriented around a limited number of heavy generators.

The Chauffeur

The provision of personnel to operate the vehicles could prove one of the most difficult problems to solve. Since it is almost impossible to hire drivers for split shifts, it probably would be necessary to employ them on the basis of two 8-hr shifts, with a few starting earlier and a few quitting later. If the demand is sufficient, it may be desirable to provide 24-hr service and employ 3 complete 8-hr shifts. The result, of course, is a serious underutilization of personnel during the off-peak periods. This problem is a common one, faced by all existing transit operators.

If the demand-scheduled system is set up to provide neighborhood service alone, a partial solution may be possible. Under these conditions, chauffeurs need not be so highly trained as regular bus drivers nor so knowledgeable about a large area as taxi drivers. Perhaps part-time personnel could be used. If such a system were to be operated by an existing taxicab company, then their current operators would have adequate experience and knowledge of the area street system. Each vehicle-operator combination could be used for the DSB or regular taxicab operation as demands warranted.

Vehicle Control

The problem of vehicle control is one of the more difficult problems encountered in the operation of a DSB system. Two basic types of information must be exchanged between the vehicle and the central control station. First, the chauffeur must be made aware of his next destination. Second, the station must know the location of each vehicle, at least at intervals, if not continuously. In addition, the chauffeur must also inform the central control of successfully completed pickups and deliveries. Many different systems are conceivable, varying in sophistication, complexity, and cost.

The simplest system, perhaps, would involve the use of two-way radios. The driver would relay his position orally to the control station, where an operator would then code it into a computer. The computer would calculate future destinations for the vehicle, and this information would then be transmitted orally from the operator to the driver. The choice of route would be left up to the driver. In the case of neighborhood service, the choice would not significantly affect the results. In larger areas, efficient operation would depend on the driver's ability to select the best route from previous experience.

A great many improvements could be made, in steps, up to what might be termed an ultimate system. Here, the vehicle would be automatically monitored continuously by radio and its position fed directly into the computer. The computer could also have stored within it the minimum time path between every pair of nodes in the service area. The desired route could be transmitted directly to the vehicle, perhaps being displayed in a schematic form on a console in front of the driver. Such a system would provide excellent service and flexible operation, but of course only at a very great cost.

Using a DSB

The most desirable method for requesting DSB service would seem to be the telephone. Callers could give operators at the central control station their origin, destination, and a desired pickup time if immediate service is not requested. The operator would then feed the information into the computer.

Fares could be collected on the vehicle, or a billing operation might be instituted whereby passengers would use credit or bank-charge cards. Alternatively, billing could be included in the caller's telephone bill. If calling from home, a passenger, after having reached a central switchboard, might dial a sequence of digits giving his origin and destination. Another billing procedure could be the use of a monthly flashpass.

Revenue

At least four sources are available to finance such a system. The most obvious is direct fare collection. There is evidence that people would be willing to pay a reasonable amount for such a service. Whether or not this would be sufficient to pay for the system is highly conjectural at this stage.

Assuming direct fare collection is inadequate, the next obvious source of funds is direct government subsidization. A subsidy to this type of system invokes fewer political problems than to a conventional system, since equal service is in fact provided to all.

A third possible source of funds would be from merchants of the area. This could be especially true of proprietors in older business districts who are faced with nearly insurmountable problems of providing adequate parking for private automobiles. A subsidy might be an attractive alternative to acquiring expensive developed property for parking lots. The merchants of the area would further benefit because DSB passengers would be constrained and encouraged to shop only within the DSB service area.

A fourth possible source is to obtain a Mass Transportation Demonstration Grant from the U.S. Department of Housing and Urban Development. It is this source which enabled the start of the minibuses in Washington, D.C. and the Skokie Swift Project in Skokie, Ill.

IMPLEMENTING A DSB SYSTEM

One possibility for implementation has been advocated and stems from the fact that most small buses use standard light-truck engines, axles, and chassis components (9). Therefore, the small buses would be compatible with maintenance facilities of small truck fleet operators. Since nearly every city of any size has one or more truck fleets, a potential exists whereby the trucking company might profitably operate a small bus transit company. It could take advantage of experience in fleet operation and also would not have to risk the entire business in a new venture. The addition of new vehicles and personnel would be only an extension to an existing plant. Some drivers could work in both operations—part-time driving a bus and part-time delivering freight.

The fleet owners may also explore the possibilities of using small buses as delivery vans during the off-peak passenger hours. The seats could be designed for quick removal through a rear door in a manner similar to the air cargo-passenger system used by the airline companies. Since peak periods of freight traffic and passenger traffic are apt to be at different times during the day, this type of operation could smooth out the peak period demand for equipment.

As well as trucking companies, an existing taxicab firm might manage and operate the system. Its experience in management and operations and its communications equipment would be valuable.

One means of expanding small bus operation would be through suburban real estate developers who could include small bus service along with the community swimming pool and par-three golf course as an enticement to buy a house in their subdivision. In addition to reducing the need for two cars, the development may fill up quicker if people did not need to purchase a second car immediately.

PRESENT SMALL BUS OPERATIONS

The feasibility of small bus operations is being investigated by the Department of Housing and Urban Development (HUD) through a research project for developing criteria for non-rail transit vehicles. They are giving special attention to a small bus door-to-door operation which could feed larger trunk line systems.

One of the more successful small bus demonstration projects is the minibus operation in Washington, D. C. This is a downtown shuttle bus system initiated in 1963 which operates over a 1.6-mile route along a major shopping street. A fleet of 14 buses operate on a 3-min headway with a regular fare of five cents. Patronage during the 1964 Christmas season averaged about 9600 daily. Normal daily loads were about 6000.

Mansfield, Ohio, (population about 50,000) is served by a fleet of eighteen Ford Econolines which have been equipped to carry 12 passengers each. Service on twelve routes is provided at half-hour intervals with some 15-min headways during the afternoon rush. Passenger counts averaged 3,000 in 1965 with a peak of 4,000 during the Christmas season. Regular fare is 25 cents. The routes fan out from a central point at the town square which is also the only transfer point between buses.

Atlantic City, N. J., has had a jitney operation since 1916. Most of the vehicles are IHC Metro buses and most are owned by the operators who have a franchise with the city. About 190 jitneys operate along a route which extends for about four miles parallel to the boardwalk. There is no scheduled headway; however, the jitneys are about one minute apart. No one stands in the jitneys and if the vehicle is full, the driver passes people wating at the curb until someone leaves his vehicle. Each jitney seats 10 people and maintenance is the responsibility of the vehicle owner; however, each jitney must pass safety inspection.

The new transit system envisaged in this paper involves three concepts which are relatively new to transit operations. The first is the use of small buses. The three examples show that such a concept is practical and economically feasible. Although the Atlantic City jitneys have been in operation since 1916, they have not received widespread attention or duplication.

The second concept is demand scheduling. In practice, this has only been evident in taxicab operation. In theory, this concept is receiving wider attention, the MIT student report being an example.

The third concept is door-to-door service. A demonstration project was recently conducted in Peoria and Decatur, Ill., which has door-to-door service on a fixed-route, fixed-schedule basis (10). The Menlo Park experiment also utilized this concept, however, the level of service was considerably below that considered in BUSTOP. The Menlo Park experiment was a physical simulation without passengers.

BUSTOP is a computer simulation which employs these three concepts. What is required now is a practical demonstration project which also employs these three new concepts.

CONCLUSIONS

Simulation can be a very effective tool in transportation planning. In many instances simulation provides an inexpensive way of evaluating alternative measures to be used in a transportation system without funding for hardware equipment. Before implementation of any demonstration projects, simulation can provide much insight into operational characteristics, equipment requirements, cost, and effectiveness. With the aid of an appropriate simulation package, cost-effectiveness relationships can be developed without the installation of actual operations.

Since the computer algorithm has been developed to solve the many-to-many problem, much more flexibility is allowed in the use of simulation to study various types of transit services. Through detailed sensitivity analysis, a more appropriate transit system with various operational characteristics can be selected for implementation.

ACKNOWLEDGMENTS

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A System for High-Speed Urban and Suburban Mass Transportation

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A mass-transportation system suitable for urban and interurban traffic is outlined which increases the carrying capacity and minimizes crowding and waiting periods. In its ultimate form, the system utilizes individual air-cushioned cars with a capacity of about 25 passengers. These cars take on and discharge passengers at the periphery of continuously rotating platforms without coming to a stop. Transfers between local cars and express cars, similarly, can be effected without speed reduction of the express cars. Car storage is provided at the several stations, permitting rapid response of the rolling stock on the tracks to passenger demand. Propulsion may be effected by "linear motors" with the "rotor" embedded in the track or similar techniques which minimize the weight and complexity of construction of the cars. It is a special feature of the system that the cars remain continuously in motion except when in storage. Furthermore, the passengers, in proceeding from the stationary center of the rotating station platforms to the periphery, where they mount the cars, are automatically accelerated to the speed of the cars, so that transfer is effected to and from relatively stationary cars.

The system described appears well adapted to automation, economic in power consumption, and can be introduced stepwise, initially utilizing conventional cars. A close examination of technical and economic problems with the aid of a reduced-scale model of the system and computer simulation of the system operation is recommended.

•WHEN launching the mass production of his Model T, Henry Ford is said to have predicted that there would be a car in every family in the United States. This prediction has come true within a life span. The automobile has become a major factor in the development of the United States and can be expected to play a comparable role in the rest of the world.

The proliferation of cars created a demand for more and better roads and these in turn produced a further demand for new cars. For a while it seemed as though this trend might continue indefinitely. However, it has become increasingly evident that the process is self-limiting. With the increase in the population density, the proportional increase in the number of cars on the roads and streets gives rise to congestion which defeats the primary objective—efficient mass transportation. This effect has become most evident in densely populated areas, particularly on the eastern and western seacoasts. The shortcomings of the automobile as key to mass transportation in regions of high population density have been accentuated by the contribution of automobile exhaust fumes to air pollution.

Paper sponsored by Committee on Future Concepts and presented at the 47th Annual Meeting.

It is thus not surprising that plans for improving the efficiency of mass surface transportation in and between big cities have redirected attention toward rail transportation, which utilizes space more economically than private automobiles and is free of other drawbacks of the latter. However, in spite of many innovations and improvements, railroads also have their own limitations. Originally it was more economic to make up trains with many cars coupled to one locomotive. This pattern persisted after the introduction of electric power for propulsion even on subway and elevated lines. Such trains create the problem of bunching people in large groups, resulting in lost time during the loading and the discharging of passengers.

The commuter desires primarily fast, reliable transportation with minimal waiting periods at any time of the day—during periods of slack traffic as well as during periods of peak traffic. The use of continuously moving single cars, separated by short intervals, could accomplish this. This solution may, however, be economically prohibitive since, for a considerable portion of the day, most of the cars would be partly or completely empty. To circumvent this difficulty on subways and high-speed suburban lines, cars may be stored at intervals along the line in a manner which does not obstruct traffic and yet permits the placement of the cars on the tracks on demand with a minimum delay. Furthermore, delays in the loading and discharging of passengers can be avoided by carrying out these processes "on the move, " without stopping the cars, by moving conveyors transferring the passengers from stationary platforms to points on the loading platform moving with the same speed as the cars. With individual cars loading and discharging passengers practically continuously at a moving platform, delays are minimized and crowding on the platforms and at the stations is avoided.

The use of automatically controlled continuously moving individual cars in combination with a circular subway station with a rotating platform is illustrated in Figure 1. The passengers arrive and leave from the stationary landing area in the center of the rotating platform, which is connected to the street level by escalators. From the center of the platform the passengers step on one of several conveyors revolving with the platform which moves them to the outer rim of the platform, where they mount the cars. If, for example, the diameter of the platform is 200 ft and it is rotating at 84 rph, the passengers at the rim will travel in a circular orbit at 10 mph. The corresponding centrifugal force acting on a passenger weighing 150 lb is only 10 lb, many times less than that experienced on a merry-go-round. Cars arriving at the station from either direction do not stop, but slow down to the speed of the rim of the platform and are coupled mechanically to it.

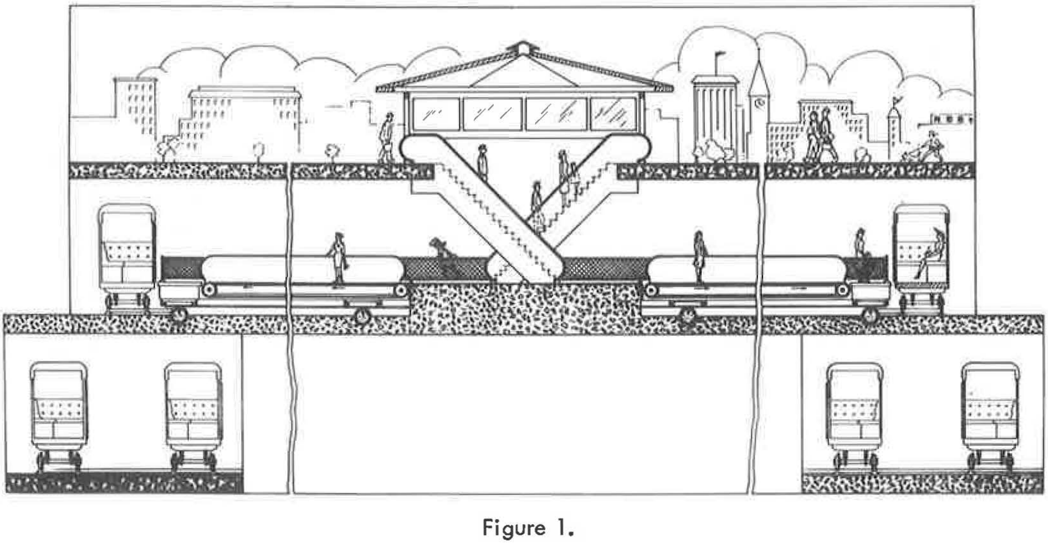

Figure 1.

Pneumatic buffers may be used to simplify the problem of coupling the cars, reducing their speed to the exact speed of the platform rim. By leaving alternate spaces around the rotating platform free during the initial attachment of arriving cars, additional cars can always find space for parking, until all spaces on the platform are taken up.

If no passengers wish to mount or leave the car, the car circles approximately a half revolution with the platform, then uncouples and proceeds to the next station. Otherwise the car remains coupled to the platform for at least one full turn, which takes somewhat less than a minute. The rim of the platform is protected by a fence with numbered gates, which are automatically opened synchronically with the doors of the cars, permitting passengers to enter the car while it is coupled to the platform (Fig. 2). If necessary, the loading period can be extended to several turns of the platform; since a platform of the indicated size can accommodate as many as 30 cars on its rim, this need not delay the arrival of other cars.

It may happen that a car is emptied and that there is no further demand for it. In this case it proceeds to the next station where it is switched from the main line and descends a down-ramp to a circular track underneath the station platform on which the cars are stored, inspected, and, if necessary, serviced. Late at night, with the falling off of demand for transportation, most of the cars may, in due time, be removed from the track and stored (Fig. 3). When the first passenger arrives and puts his token in the turnstile slot, or the requirement for space becomes higher than is available, a car from the nearest station will move from the storage ring onto the track, pick up the passengers, and proceed on its route.

At the peak of traffic all cars may be in service and arriving at the stations a few seconds apart.

With the present state of development of electronics it should not be difficult to design a completely automatic system controlled by a computerized dispatcher. The traffic program will be dictated by past experience, with corrections applied for any special circumstances prevailing on the particular day. The knowledge of the relative positions and speeds of all cars on the track should make it possible to operate the entire traffic at maximum efficiency. In many

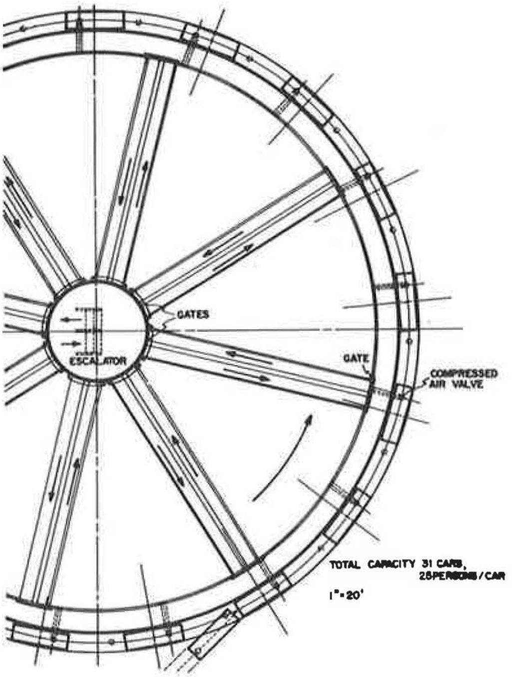

Figure 2.

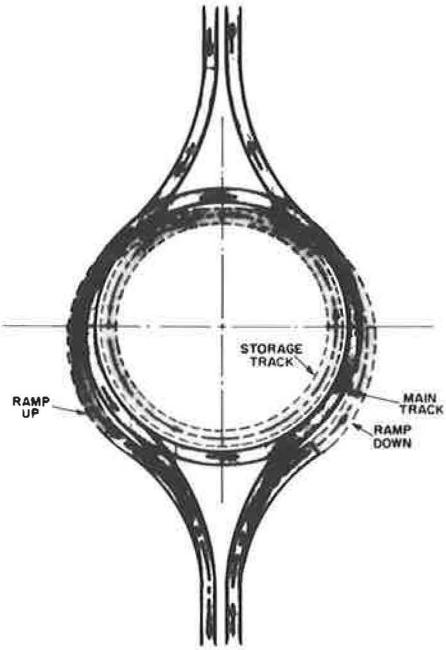

Figure 3.

respects the problem resembles those encountered in the electronic booking of seats on air lines and in the automatic control of automobile traffic (1).

In the first phase of the system study, existing rolling stock could be used, replacing manual control by electronic remote control. Rails and propulsion would remain the same as at present. Switching would be controlled by remote control and computer. Emergency changes in the schedule of any car could be initiated by passengers from the car. New cars specially designed for the system would be smaller (e. g., for about 25 persons), lighter, and would have wide doors on one side only, with seats arranged to facilitate rapid loading and discharge of passengers, (Fig. 4).

The loading stations with their rotating circular platforms could be located under city squares or under the centers of city blocks so as to avoid interference with pipes and other services distributed along the streets. Multilevel intersections would become unnecessary since cars of several lines could use the same platform. Furthermore, individual cars could be routed over a number of different intersecting lines, moving from one to another, avoiding the necessity of passenger transfers.

The platform can be rotated supported by wheels on a circular railroad track, by rubber tires on a concrete roadbed, or, preferably, on an air cushion under the rim of the platform.

The introduction of continuously moving cars permits yet other radical modifications. A major portion of the power required for surface transport is expended in overcoming mechanical friction. At the moderate speeds of city traffic or suburban air resistance accounts for only a minor fraction of the total power consumption. Furthermore, the propulsion machinery in standard cars makes them heavy and expensive.

To overcome the loss of power from mechanical friction of wheels on rails, vehicles could be moved on air cushions, as exemplified by tracked, air-cushion vehicles (A. V. C.) such as the experimental French Aerotrain and the British tracked Hovercraft (3). Propulsion by wheel traction could be replaced by methods outlined in the same report, such as the linear induction motor or the linear air turbine. Use of the latter would presuppose the discovery of a method of suppressing the noise of high-velocity air.

Since the cars are always in motion except when they are in storage, the supply of air for the air cushion can be created by the motion itself, through the use of a properly designed scoop with variable orifice in front of the car. The air is pushed by the ram action of the moving scoop into the space between the bottom of the car and the smooth surface of the track, which is lined with magnetic pole faces, similar to the unfolded rotor of a multiphase motor. From here air leaks out through the space between the edges of the car and the surface of the track. Since both the track and the bottom of the car are smooth, the gap through which the air escapes could be small, about $1/4$ in. or less, lined by rubber edges. The lifting pressure should be proportional to the weight of the car and its passenger load and is controlled by the variable orifice of the scoop. If the weight of the car is 5000 lb and that of 25 passengers is also 5000 lb, the pressure required to lift the total load of 10,000 lb, for a bottom area of the car of 120 sq ft, is a fraction of a pound per square inch. In part this pressure is self-adjusting, through the variation in the width of the air gap between the edges of the car and the track with the load of the car, in part it is regulated by changing the orifice of the scoop, operating from the air pressure, due to the motion of the car.

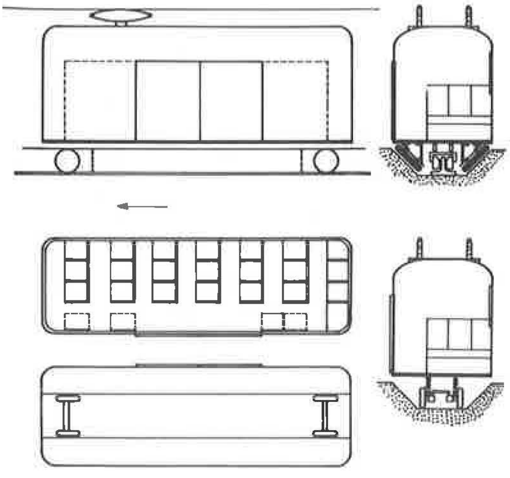

Figure 4.

Experimental work with the linear motor is carried on in this country and abroad, particularly in France. In the United States, the work is done at several places. A recent report (2) summarizes the result of this study: "The size and weight requirements for a linear induction motor and the necessary speed control system are consistent with those available in projected HSGT vehicle designs. The linear motor can provide the output power necessary to drive the HSGT vehicles at speeds in excess of 400 mph." Small-scale linear motors are on the market in this country (for instance, by the Electro-Nite Co. in Philadelphia for driving a recorder pen).

The use of a scoop for generating an air cushion is well known; the question is whether the speed of the car when coupled to the terminal platform is sufficient to maintain the required lifting pressure. If it is not, additional lift could be provided by tapping the compressed-air reservoir required for floating the platform itself, to the appropriate places for releasing the air under the individual cars, coupled at points on the circumference of the platform (Fig. 2). The air release is initiated and controlled by cars at the points where they are coupled to the platform. The rotation of platforms can be synchronized and serve as a clock for the whole system.

The motion of the cars to and inside of the storage ring could be provided by a conventional moving cable with sleeping coupler, as used in cable railways, or a combination of short cables at the entrance and exit of the platform and coupling with the platform itself in the remainder of the storage ring.

Pneumatic catapults may be employed to increase the acceleration of the cars leaving the platform.

The carrying capacity of such a system is determined largely by the capacity of the individual platforms. Since the maximum number of cars attached to a platform with a diameter of 200 feet is about 31 and all of them make one full turn with the platform or pass through the station in one minute, the carrying capacity in both directions is 31 (cars) × 25 (persons) × 60 (minutes) = 46,500 persons/hour or 23,250 persons/hour in each direction.

The capacity of the system can be increased by increasing the speed of loading and, as in present systems, by the addition of express lines. In this case only two end stations would be needed for the express cars, since transfers from local to express cars can take place at full speed, by hitching cars started from local stations to the express cars at predetermined points on parallel tracks. The express line could be either on both sides of the local track or under it.

The general operation of the system can be visualized as follows: Suppose the system is idle and that there are no passengers and no cars on the track. The first passenger arriving at any of the stations puts his token in the turnstile slot; this token, purchased from an automat or cashier, has recorded on it the point of departure and the destination of the passenger. After being admitted by the turnstile the passenger steps on the escalator and is delivered to the stationary center of the rotating platform. Here, one of several gates, determined by the destination on the passenger's token, admits him to a conveyor which delivers him to a car at the rim of the platform. At the same time, the deposit of the token initiates the transport of a car from storage at an adjoining station to the loading position on the rim of the platform and the platform gate and car doors open simultaneously to admit the passenger. If the system is already in operation, when the new passenger arrives and several cars are already hitched to the platform, a lighted number on the appropriate conveyor gate routes the passenger to the car which has space for him and will deliver him to his destination. Signaling devices on the cars would be provided for emergencies and to permit passengers to dismount before arriving at the destination indicated on the token.

It is desirable to recover the power released during deceleration of the cars by employing magnetic braking and pumping the power back into the power line, as is done in Swiss mountain railways.

The guidance is provided by the air-cushioned track. Cars still retain wheels but they remain idle during high-speed cruising, since they are lifted from the track by an air cushion; wheels, however, will still be used in storage, where the air cushioning is unnecessary.

This system is appropriate not only for subways, but also for high-speed surface transport. In the latter case the way should be covered by a cylindrical plastic canopy to protect it from the weather.

The preceding paragraphs have sketched a rough outline of a novel system of transportation. Unquestionably, many technological difficulties lie in the way of its realization; however, it is hard to foresee whether these difficulties are surmountable unless the system is tested. Tests could be carried out on a reduced-scale of the system at comparatively low cost, and the preliminary analysis of optimum operation by computer.

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Small Car Automatic Transit

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•WITH continued urbanization there is mounting concern about circulation and its relation to the quality of metropolitan living. Air pollution, traffic fatalities, and the relative immobility of a substantial part of the population are some of the deficiencies. Such problems have spurred millions of dollars worth of federally sponsored research in quest of a transport breakthrough.

No one knows whether we shall be able to achieve new systems that can transport persons in metropolitan areas quickly, safely, and economically in such a way as to meet the real needs of the people and at the same time contribute to good city planning. It may turn out that great improvements in circulation would be feasible only with great changes in our environment and habits, changes on a par with those that have attended the dominance of automobiles. Thus, to have the styles of living that are popular today, it may be necessary also to accept environmental conditions much as they now are. Nonetheless, it is possible too that technological developments complementing a shift in social attitudes could bring about the transport breakthrough sought.

One candidate among ideas for a breakthrough is driverless, individualized transport. In the form in which this concept is discussed here it is referred to as small car automatic transit, or simply "SCAT." In familiar terms it is a merging of taxi-like aspects with features of the Minirail transit installations at the Expo 67 in Montreal. Defined formally, SCAT is a system of small cars capable of unattended operation individually over an urban network of exclusive trafficways. (In this paper cars run only on tracks, vehicles are driven on roads, and dual-mode conveyances are adaptable to either. Transport refers to all powered modes, as used for trips within a metropolis, and transit is any transport mode that places on its user no driving or parking responsibilities and no social relationship to a driver.)

Small car automatic transit is examined primarily in the physical context of the middle-sized metropolis. Such places, according to one viewpoint, should be planning even now for rapid transit. Timely development of SCAT technology, however, could open a new course for transit investment. Rather than the traditional one or two high-capacity transit lines connecting a handful of stations, a broad network of SCAT facilities would connect a great many localities—with a service having attributes of rail transit. Accordingly, the SCAT route networks considered here are roughly comparable with the routes of present-day bus transit operations.

DESCRIPTION

The concept under consideration is shown in Figure 1, an unsophisticated illustration from a decade-old proposal. A SCAT installation comprises a fleet, facilities, and plant—with a work force to maintain service. The small automatic cars of the fleet are anonymous; unlike private automobiles, no SCAT car retains a special relationship to any one person. In an installation, the facilities are the public portion: the trafficways and stations, and the route junctions where cars may change course. The plant includes car storage yards and maintenance shops.

Although SCAT technology might be applied to a single looped route (resembling the Expo Minirails), the usual installation is better thought of as a network of trafficways

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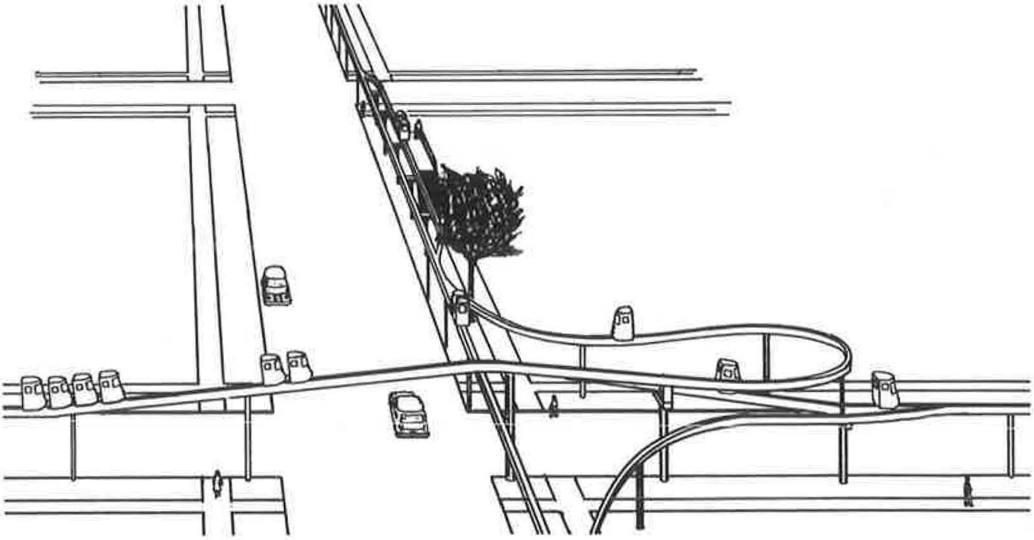


Source: Northwestern Engineer, XVI (August, 1957), p. 14.

Figure 1. Individualized transit facilities and cars.

interconnected at junctions. The facilities are effectively separated from external interference. Any car can go anywhere on them, with or without an occupant, permitting the recirculation of empty cars according to localized demands. Except as necessary, however, cars do not keep traveling, but remain in stations (or in yards) available for use. Because people board and leave cars only at stations, mainline traffic is able to move freely past stations and is essentially non-stop. After a person has occupied a waiting car, closed its door, and pressed its starting button, automatic controls take the car out into a gap in the mainline traffic. The car travels along the route it is on unless commanded to turn, which the rider accomplishes merely by pressing a turn button in the car. (The additional feature of destination preselection and automatic routing is regarded as an option which might be worth its expense.) By commanding a turn, when approaching his destination, the rider causes his car to enter the station and bring itself to a stop. The car is simply left there, to be used by anyone else or perhaps to be called away by a station downline that momentarily lacks cars.

To recount the features of small car automatic transit, service is available at all stations at all times. Like a self-service elevator, a SCAT car is easily operated, but it is occupied exclusively and not shared with unfamiliar individuals. The cars always remain a part of the installation; nobody parks a car nor does he drive one home. Thus, the breadth and coverage of service is closely related to the facilities provided.

SCAT NETWORKS

Most of the route mileage of an extended SCAT installation is likely to serve that portion of the metropolis, here termed the city, which is characterized by its density and relatively regular and permeable street pattern and which includes many square miles of residential settings as well as the central business district (CBD). Given peoples' interwoven travel directions, SCAT routes might reasonably conform to a grid-like arrangement rather than following the strongly radial pattern of conventional transit. Figure 2 illustrates a portion of a so-called citywide SCAT network, with cell size increasing from one or two blocks in the downtown core to perhaps half a mile at the margins of "city" development.

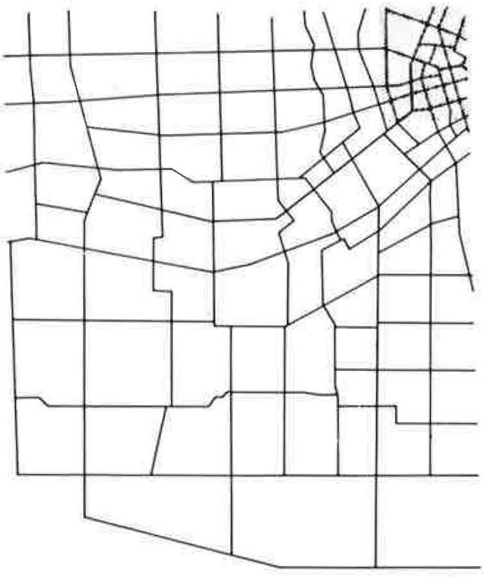


Figure 2. Portion of citywide route network.

The merits of the grid have been recognized in the Transgrid concept (1). As proposed, the Transgrid has essentially a uniform cell size all over the metropolis. Thus, only two or at best four of the individual routes can serve the CBD, and they obviously will need capacity considerably higher than that for routes at the periphery of the Transgrid. This suits the Transgrid principle of adaptability to entirely different technologies for the individual lines; and because they are therefore "uncoupled," patrons change route by getting off and transferring. By contrast, the single SCAT technology allows universal "coupling" or interconnection of routes. This facilitates spacing the network to local conditions, lets riders avoid transferring, and permits servicing the entire fleet in one shop.

Two elementary types of SCAT route junctions are shown in Figures 3 and 4. Their curving "junctures" function like storage and turning lanes in a road junction, letting mainline traffic stay essentially free-flowing. If two-way routes consisting of side-by-side mainlines are involved in a junction, it is likely to be appreciably more complicated as in Figure 5, a one-way/two-way junction that requires both an overcrossing and a turnback. The geometrics of a two-way/two-way junction would be formidable in the restricted space usually available. Thus, the avoidance of junction complexity pleads for a SCAT network composed primarily of one-way routes, despite some inconvenience to users.

In an actual SCAT installation, each station would be located with regard to factors such as the local street pattern, maximum walking distance, and proximity of traffic generators. Although station placement is thus indefinite, one may assume that a car traveling along a route would pass a station about midway between successive junctions. In the citywide SCAT network (which is grid-like) this arrangement of stations, despite their wide spacing, tends to optimize coverage and walking distance. The workability of more frequent SCAT stations is under consideration, in response to a suggestion for station capabilities every 20 feet along a route (2, p. 2).

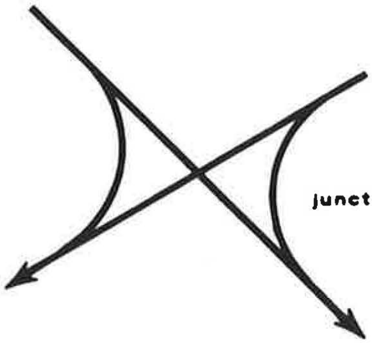


Figure 3. Simple route junction: intersection.

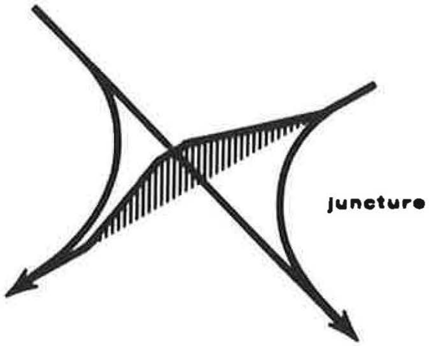


Figure 4. Simple route junction: overcrossing.

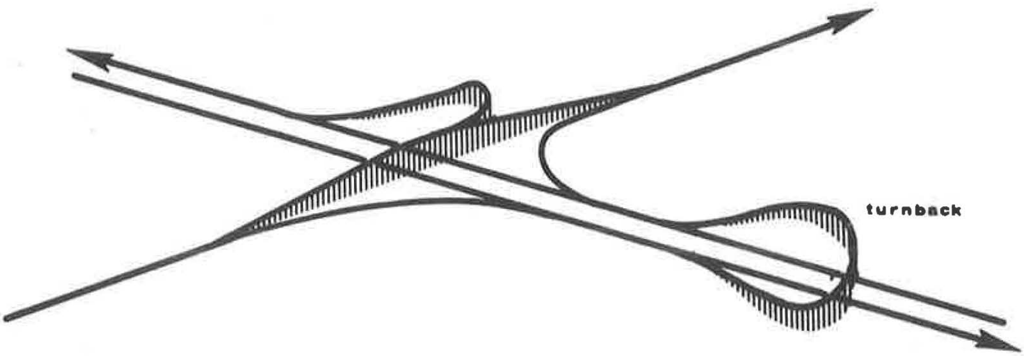


Figure 5. One-way/two-way junction.

Analysis of urban transport systems has developed the notion of a hierarchy of networks differing in their celerity and accessibility, and variously suited to longer or shorter trips. As Haikalis notes, there is no real need for systemwide uniformity in operating speed (2, p. 4). Yet a hierarchy of three standard speeds seems desirable in engineering terms, and is conceptually simple. The standard operating speeds proposed for SCAT service are:

On express routes	45 mph
On the regular network	27 mph
On most facilities in downtown	11 mph

Express SCAT service would tend to attract much traffic to facilities of inherently lower capacity. Fortunately, this tendency would be offset by the absence of any stations on express mainlines and by the limited number of connections with the regular network. Ideally, the spacing of express routes should reflect an appraisal of the economic and social costs of speed as well as its farebox value; probably a spacing of 2 to 3 miles would be appropriate between the two-way express facilities. If their siting were governed by special restrictions, however, the SCAT express network might be shaped almost entirely to such freeways, railroads, suburban highways, and other linear features as were available.

The usefulness of a network expands with its size, justifying extension of SCAT routes beyond the citywide network out into the periphery of the middle-sized metropolis. While this suburban portion is sure to have some older towns (resembling tiny cities), most of it is recent development—chiefly commercial-industrial frontage along highways and residential subdivisions elsewhere. Shaped by dependence on automobiles, the road pattern and less dense spread of the contemporary suburban setting are factors adverse both to walking and to transit service. In light of economic and right-of-way considerations in this setting, suburban SCAT routes would probably be confined to the arterial highways.

Figure 6 illustrates the idea of a metropolitan SCAT network—as applied to the CBD and one quadrant of an actual middle-sized metropolis. The citywide network appears as an imperfect grid, warped to the features and available rights-of-way of the real city. One-way routes are prevalent in this network outside of downtown. The suburban extensions form a loose network composed generally of two-way routes along highways. Primarily these facilities would serve places like shopping centers, large plants, and older towns (where modest networks may be provided). Stub-end express routes, like the airport extension, would also have a two-way regular mainline for access and for reserve capacity.

Figure 6. Concept of SCAT metropolitan route network (one quadrant only).

FACILITIES

The notion of unattended conveyances operating among vehicular traffic in the streets is rejected here, out of deference to the capriciousness of street users—whether driving or afoot. SCAT cars must use off-road trafficways. To emphasize that these SCAT facilities have to be discussed as tangible structures, they will be termed "tramways" (after tram, in the sense of a beam).

The scale of the tramway is set by the size of SCAT cars, which would be as tall as a schoolchild and as wide as a stout adult. As a transport facility, the tramway is modest in its scale. Essentially, though, the SCAT tramway is also an urban utility line, and it would rank among the largest of such lines. The width of subsurface tramways (tunnels) would be further enlarged by walkway space alongside the car-clearance envelope. Although above-street tramways would occupy less space, quite evidently the SCAT tramway in general would not be fitted into most metropolitan settings as readily as utility lines are.

Like any transport facility, the SCAT tramway would occupy a right-of-way. Certain categories of right-of-way would be suitable only for tramways built at particular levels, as suggested in Table 1. Whether an express (x) or a regular (r) tramway would fit a given right-of-way and level depends on network and aesthetic factors. The "easement" right-of-way concept is applicable in settings composed of detached houses.

TABLE 1

SUITABLE TRAMWAY LEVELS

Level	Right-of-Way				
	Street	Freeway	Railroad	Easement	Private
Elevated	r x	x	x r		
Surface		x			x r
Subsurface	r	x		r	

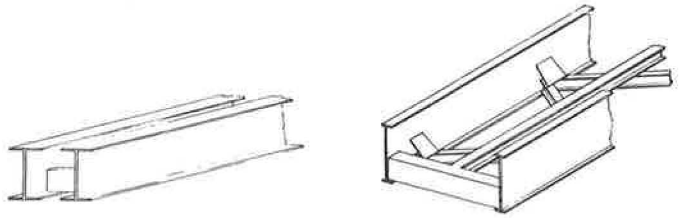
x = express, r = regular.

There, tramways might be tunneled in easements located either between houses or along backyard lot lines, and would cross streets just beneath the pavement. Despite the construction economy of surface tramways (merely trackage protected by adequate enclosures), there are few rights-of-way where a long barrier to surface movement is acceptable.

Among the above possibilities, only the right-of-way of streets is believed to be practical for most of the routes of a citywide SCAT network. Streets are nearly ubiquitous and their rights-of-way already have a public status for transport purposes. Accordingly the rest of this section on facilities presupposes their being located within the right-of-way of thoroughfares—chiefly arterial streets—above or beneath the surface.

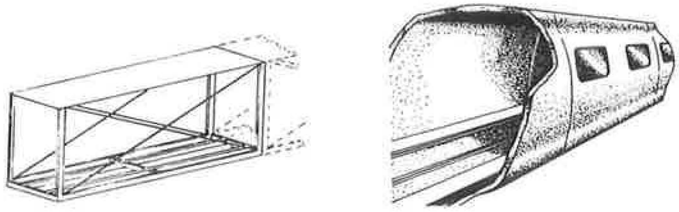
Several types of tramway spans are shown in Figure 7. Figures 8 and 9 show sectional views of elevated and subsurface tramways in relation to a street. (Details of an actual installation could differ widely from those sketched, of course.) The interval between supporting columns or bents would range upward from 20 feet.

The structural design of tramways would be a more straightforward engineering task than finding a place for them in the public right-of-way. One complication is that existing features along the street would have a kind of seniority over the planned tramway, forcing on it most of the compromise of fitting in among them. Unlike a gas main,



a. Minirail beamway

b. Veyar truss



c. Roofed through truss

d. Teletrans tube

Figure 7. Types of SCAT spans (not to scale).

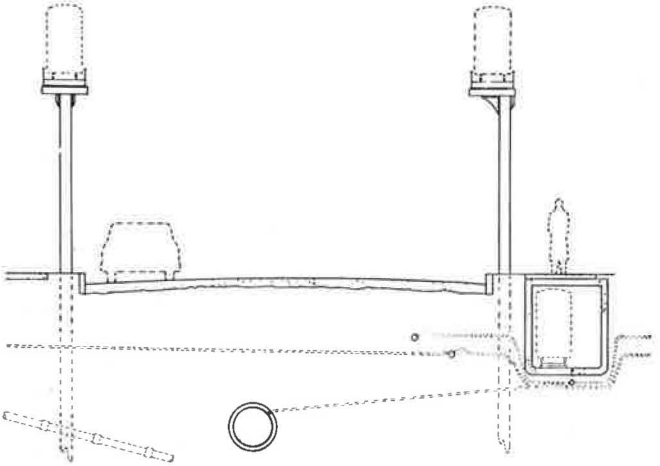


Figure 8. Street cross section with elevated tramways and subsurface tramway under sidewalk.

moreover, a tramway could not be offset abruptly around obstacles but would have to be deviated gradually to avert them. For elevated facilities in particular, trees are a further planning difficulty. Much citywide route mileage would follow arterials that are more or less residential, making the preservation of trees extremely desirable.

One may anticipate a substantial divergence in the methods of producing elevated and subsurface tramways. The designers of an above-street tramway, for all the trees

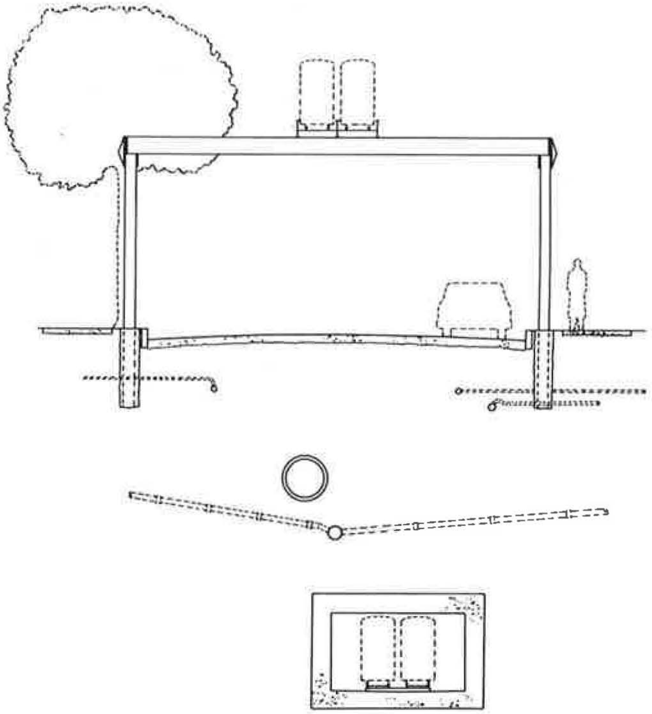


Figure 9. Street cross section with elevated tramways on "bent" support and subsurface tramway.

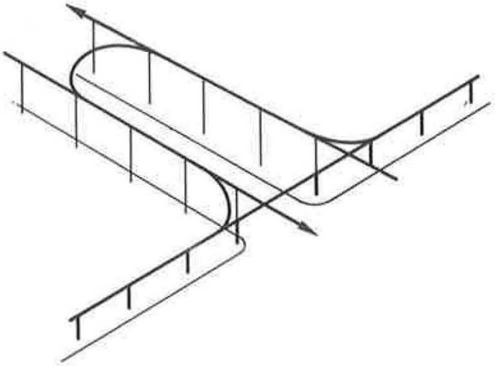


Figure 10. Portion of elevated two-way CBD junction.

and wires and luminaires encountered, would at least be coping with known and visible obstacles. By contrast the subsurface tramway would typically have to be fitted in among a clutter of mains and drains, sewers and conduits—mapped with varying inexactness, if mapped at all. Once the exact tramway alignments had been defined, elevated spans or tunnel sections complete with track might be fabricated in a mechanized or even semi-automated shop. Completion of an elevated tramway would require little field work beyond setting the supports and erecting the spans. Installing tunnel sections to exact alignment in the ground would entail much field labor, however, with work constantly subject to much higher risk of disruption from breaking a utility line. Considering the difference in labor inputs, the elevated tramway would seem likely to have a lower unit cost. Further development of remotely controlled tunneling methods might eventually permit building tramways beneath all the utility lines (as in Fig. 9) at reasonable cost, for the tunnels proper. Nonetheless, these deep tramways might incur substantial costs on items such as drainage and stations.

At either level, junctions are difficult elements in a SCAT installation. Their junctures demand a prescribed amount of space for transitions to and from the mainlines and a curve whose sweep is dictated by speed and the dynamics of a smooth ride. Because each juncture (or turnback) may add visual bulk if above the street or may entail utility relocations if beneath it, simple junctions are preferable to those having two-way routes (Fig. 5). Simple one-way junctions are also preferred because their mainlines need not cross over each other but may intersect at the same level.

It is this kind of simplified junction (Fig. 3) that fixes the basic citywide network as a grid of one-way routes, alternating in direction. Accustomed to bidirectional travel networks, the public would find these one-way SCAT routes somewhat inconvenient, yet this fault seems more acceptable than the alternative of serious junction problems. Two-way routes need not be entirely excluded from the citywide network, however, if it is elevated. Their side-by-side mainlines might be appropriate along major arterial streets whose width and abutting development can accommodate the bulkier junctions. In the CBD, the SCAT routing situation is quite different, owing to the large volume of travel at the beginning and close of the work day. Analysis suggests that a closely spaced grid of two-way routes is needed. These routes could take the form of single elevated tramways directionally paired along opposite sides of a street, and overcrossing as shown in Figure 10, with compact inclined junctures appropriate to the reduced operating speed. A subsurface network on this pattern is judged to be impractical.

Assuming that downtown SCAT facilities must be elevated, how do elevated and subsurface systems generally compare otherwise? Operationally a subsurface SCAT system should be more weatherproof; indeed, unenclosed elevated facilities are exposed to snow and fog, and may involve special measures if cars are to have enough traction to run in the face of a gale. On the other hand, in case of a blockage or other emergency, the elevated facilities are potentially more accessible for being cleared, and their exposure to public surveillance should lessen policing requirements. Because road vehicles may be 12 to 14 feet tall, the typical elevated station cannot have its platform lower, which poses the problem of service for persons unable to climb stairs to that height. By contrast the platform of a shallow subsurface station could be but half that distance from the surface—a climb of only a dozen steps. From an aesthetic standpoint, a subsurface installation has the merit of being out of sight except for its stations. There is another aspect of aesthetics, however: how many riders would prefer the view inside a tunnel to that from an elevated tramway? Moreover the very visibility of the elevated system makes it far more intelligible to patrons in the relationship of its routes to one another and to their surroundings. Considering all of the comparative features of the alternative levels, neither appears to be clearly the better.

In summary, SCAT facilities typically would be located within street rights-of-way; the appearance of elevated facilities is a major concern, as are subsurface construction difficulties; and network design is influenced by the desirability of geometrically simple junctions. Based on what is currently known about small car automatic transit systems, the elevated level is believed for economic reasons likely to prevail in any metropolitan installations that may be built.

CAPACITY

The capacity of SCAT is first established here for mainline operation, and then for network traffic; station and junction capacities are not discussed. Attention focuses on conditions during periods of peak demand when capacity would be most needed. In the context of this treatment, mainline traffic is regarded as a steadily moving stream whose composition is ever changing as cars enter or leave at stations and junctions along the way.

The question of how much traffic a SCAT facility ought to be able to handle raises some issues that would be met in system design work and the development of SCAT technology. For example, every interruption in the mainline track, like switches, presents a finite (though very small) risk of serious failure. That possibility should give pause to proposals for a tightly packed traffic stream. The whole question of the economics of control sophistication has great importance from a system standpoint. Should controls be relatively simple, requiring liberal gaps between moving cars and yielding a somewhat jerky or "stiff" performance? Or should controls have the complexity (and cost) needed to handle higher traffic volumes more adroitly while providing a smoother ride? Befitting this preliminary survey, SCAT performance specifications are inclined to be conservative.

Mainline Capacity

The defining of mainline capacity begins from a regard for safety: How abrupt a halt may be imposed on a dozing or inattentive rider? The stopping distance for an emergency halt fixes the (minimum) "safe-gap" allowable between successive cars. A quite arbitrary critierion for emergency halting has been set as:

> In effect, on perception of an emergency the car instantly begins to halt at a braking rate that increases uniformly from 0 to 0.4 G (or 8.8 mphps) in 1.0 sec, remaining at 0.4 G until the car has halted.

Here are the approximate safe-gaps and halting times at the three proposed standard operating speeds:

	Downtown	Regular	Express
Mainline speed (mph)	11	27	45
Mainline speed (fps)	16	40	66
Safe-gap (ft)	18	79	200
Halting time (sec)	1.8	3.6	5.6

Mainline capacity, in the sense used here, specifies a practical ability to move persons. Cars are considered to be 7 feet long and to seat only one rider (although tandem seating could be accommodated). If the cars operate singly (no trains), a maximum volume of riders may be calculated for these assumed conditions. Seventy-five percent of this maximum is taken to be the capacity. It allows for spaces in the traffic stream to admit cars whose riders wished to enter from stations or other routes, and also for

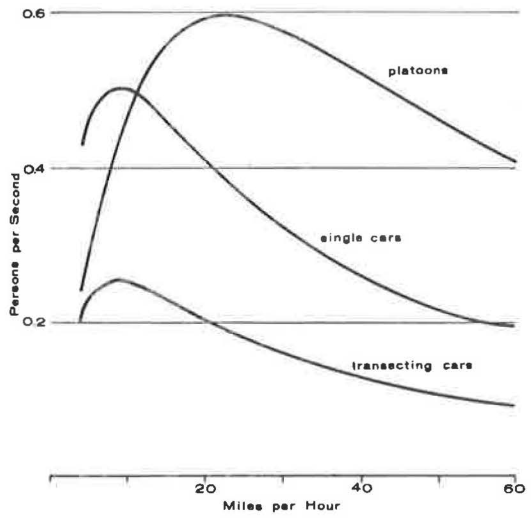


Figure 11. Mainline capacity relative to speed and operating method.

an occasional empty car diluting the flow of riders even in peak-direction traffic. The single cars curve in Figure 11 shows capacity attaining a peak value of 0.5 persons per second at a mainline speed of 9 mph.

If a SCAT junction is to have two mainlines that intersect, their capacities must be based on the ability of their traffic streams to cut across or transect each other safely. This requires that the gaps between successive cars be lengthened greatly—to two safe-gaps plus a car length, according to a reasonable criterion (Fig. 12). Application of this criterion to single-car traffic results in the low capacity per mainline shown in Figure 11 by the transecting cars curve.

Mainline capacity through an intersection may be improved by aggregating the traffic into groups or platoons (Fig. 12) so that the necessarily lengthened gap is shared by several cars. Although in a platoon, the individual cars (as well as 2-car and 3-car trains, if desired) would still have complete independence of routing and station choice, just as in single-car traffic. The controls would handle every platoon as though equal in length to the permitted maximum of 6 cars. Even in peak traffic, however, most platoons would have to consist of fewer cars in order that trains and cars might enter traffic promptly by joining almost any platoon. Based on a limit of 3.6 riders per platoon, the capacity of a mainline that could safely intersect others is given by the appropriate curve in Figure 11.

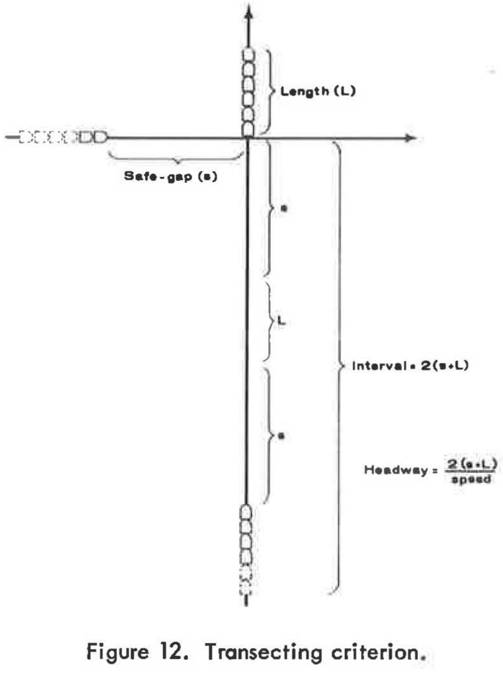


Figure 12. Transecting criterion.

The platoon method of operation obviously calls for sophisticated controls. It would not be restricted to either dense or transecting traffic, of course. The lengthened gaps between platoons would provide considerable slack in the traffic stream. This slack could be drawn upon by cars for slowing on the mainline prior to turning from it, aiding the compactness of junctions and stations.

Network Capacity

With mainline capacity established, the adequacy of a citywide SCAT network under peak traffic may now be examined. There are two approaches to doing so. Assume in either case that SCAT carries half of the person trips. The network may be thought of as a grid of alternate one-way routes. They consist of intersecting mainlines having a capacity of 0.58 persons per second or 2,100 persons per hour.

The first approach determines the widest spacing of routes just adequate for an idealized, essentially homogeneous urban region. The network is a regular grid of square cells. Trips commence uniformly in space and time, and travel along one-way trafficways. On these facilities the average volume V may be shown to be:

$$V = \frac{LT}{w} \text{ (trips/unit time)}$$

where
L = average trip length on network,
T = tripmaking per unit time, and
w = total length of trafficways.

Tripmaking is related to area and population density and to the people's trip-commencing rate, while the grid size determines trafficway length:

$$T = ADC \qquad w = 2\frac{A}{S}$$

where
A = area of region,
D = population density,
C = trip-commencing rate per person per unit of time, and
S = length of side of grid cell.

Then the required grid spacing or cell size, $S = 2V/LDC$, if the trafficway capacity is set equal to average volume V.

To determine route spacing requires a knowledge of the trip-commencing rate. Metropolitan transport surveys have generally found that the peak-hour trip-commencing rate for transit and auto travel is in the range of 45 to 55 person trips per second per million population. The expression for S, evaluated with a SCAT trip-commencing rate of 25, density of 10,000 persons per square mile, and average trip of 4 miles (allowing for network circuity), indicates a grid spacing of some 1.2 miles.

That spacing assumes ideal homogeneity. Suppose, however, that 40 percent of the total traffic went along crosstown routes while 60 percent were radially oriented toward downtown, with a 60:40 directional split. Then the radial routes would have to be spaced 0.8 mile apart at the assumed population density. Appreciably higher densities are not usually found over large areas in middle-sized cities. Therefore, a SCAT network based solely on coverage policy—with cells $^3/_8$ to $^1/_2$-mile square—should have adequate capacity outside of the CBD.

The other approach to checking network capacity is based on the observed vehicular volumes (ADT) on arterial streets. Imagine a grid of two-way arterial streets, overlaid with a similar grid of one-way SCAT routes. For analytic purposes the total daily vehicular volume on each of the arterials would be essentially unchanged whether they were all two-way streets, or alternately one-way facilities in the manner of the SCAT routes. (To illustrate, the combined northbound traffic of a pair of two-way arterials may be placed on one of them, while the other arterial then carries all the southbound traffic.)

To compare the person-capacity of the arterial streets and the SCAT facilities, first assume that each arterial has a two-way ADT of 10,000 vehicles, with 11 percent of the daily volume in the peak hour, directionally split 60:40. Further, assume a peak automobile occupancy rate of 1.33 persons (exclusive of trucks and buses) and assume that the resulting peak-direction flow of persons is increased 25 percent by transit riders. Then two adjacent arterials have a combined volume of 2,200 persons per hour in the peak direction. If 50 percent of that volume is assigned to the single equivalent SCAT mainline, slightly more than half of its capacity is used. Apparently, then, a one-way SCAT route network, coinciding with a two-way arterial street system whose vehicular volumes had generally not exceeded 19,000 ADT, should be capable of serving about half of the peak-period travelers.

Downtown, the SCAT network consists of reduced-speed mainlines rated at a capacity of 0.49 persons per second (1,760 persons per hour). If it were to carry half of the peak-period person travel—including all of the present-day street transit travel, assumed to be one-third of the current travel there—a one-way SCAT network could suffice only if vehicular volumes on the corresponding streets had not been greater than roughly 11,000 ADT. Thus, it appears that although the downtown SCAT network would be finely meshed (with cells containing only a few city blocks), much of the network in and near the CBD would have to consist of two-way routes.

The portion of a metropolitan SCAT network shown in Figure 6 is based upon an actual middle-sized city whose arterial vehicular volumes are known. According to the ADT-based criteria presented above, SCAT facilities outside the CBD appear adequate. Similarly the rather irregular SCAT network within downtown offers enough mainline capacity, but its ability to handle peak turning and station loads was not examined. Downtown cordon count data for the city in question suggest that SCAT capacity into and out of the CBD should, in the aggregate, be sufficient.

ECONOMICS AND SERVICE

No attempt has been made to estimate the economics of a SCAT system having the attributes discussed. Nonetheless, the partial metropolitan network mapped in Figure 7 does allow a rough check, in terms of the limiting cost and investment at which this SCAT installation could break even financially. With this same network some indication can also be obtained of the comparative service afforded by SCAT and by autos.

For this comparison, trips were traced along mapped streets and SCAT facilities to simulate travel via each mode system between the same origin-destination pairs. Ten such pairs were used, their straight-line lengths aggregating some 30 miles and having a length distribution like that of reported person trips. Trip end locations were essentially random with respect to transport facilities, while reflecting actual travel patterns (with a single trip end in the CBD). No trip used an express facility. Travel time for the alternative systems was synthesized according to these parameters:

Automobile	SCAT
Average running speed: 9 to 28 mph (varying by distance from CBD)	Mainline speed: 27 mph (11 mph in CBD)
Terminal delay: 120 to 20 sec (decreasing farther from CBD)	Penalties: 70 sec for both stations, plus 10 sec per turn
	Walking: 4.6 ft/sec (3.14 mph)

Although approximate, the test indicated that the SCAT system would compare favorably with autos in travel time. On the average (door-to-door), the trip by auto saved not quite five minutes over the average 19-min SCAT trip. (One of the factors slowing SCAT was routing indirectness, its network/direct travel ratio being 1.38 compared with 1.21 for the auto trips; the other factor was walking, which cost an average of 3½ minutes per trip end, but which amounted to 14 minutes on one of the SCAT trips.) Survey data for the actual metropolis show that the average bus trip there reportedly takes somewhat longer than half an hour altogether.

For the economic investigation, the facilities in Figure 6 were expanded to represent a full metropolitan installation roughly 12 miles in diameter. This indicated a system equivalent to some 525 miles of one-way mainline, with 1,000 stations and 540 junctions. The unit cost of an average station and junction, respectively, may be taken as equal to 0.1 and 0.2 mile of single-direction tramway; total expense of system service (including inspection and renewal of fleet and controllers, plus power and general maintenance) is considered to be 3.33 times the carrying charges on the facilities alone, based on cost estimates for a particular system (3, p. 126 and 128). The annual amortization and operating expense of the system is therefore equivalent to the price of about 180 miles of one-way tramway.

TABLE 2

BREAK-EVEN UNIT COSTS

Fare per Person Mile ($)	SCAT Usage of Total Travel (%)	Unit Cost of Tramway per Mile of One-Way Mainline ($)
0.04	20	55, 000
0.04	50	137, 000
0.06	33	137, 000
0.10	20	137, 000
0.10	50	340, 000

Within that portion of the actual metropolis supposedly served by the test SCAT installation, known person-trip interchanges via all transport modes between all districts are estimated to generate about 3 million straight-line person miles of travel on a work day, or some 3.4 million network miles on an AADT basis. If this travel is arbitrarily split among autos and SCAT (superseding buses) and the system revenue is calculated for several rates of fare, the break-even unit costs of tramway are as given in Table 2 for several combinations of SCAT usage and fare.

SCAT service would differ so much from taking a bus (or driving in city traffic, for that matter) that usage can only be guessed. Besides the superior speed of the new mode, several other factors may be weighed. Currently in the middle-sized metropolis the usage of public transit rarely exceeds 10 percent, riders often pay more than $0.10 per mile on the bus, and auto-driver trips to "serve passenger" are as numerous as transit trips. It seems reasonable, then, to guess that mainlines should not exceed a unit cost in the range of $100,000 to $150,000 per one-way mile if a metropolitan SCAT installation is to pay for itself entirely from fares. On a self-liquidating basis the installation in question must not exceed a total investment of roughly $100 to $150 million, or about $300 per capita for the 450,000 population in the service territory.

These sums are not cost estimates. They are more nearly guesses of the cost limits above which financial self-sufficiency would be unlikely for a particular metropolitan SCAT installation.

DUAL-MODE TRANSPORT

In a small car automatic transit installation having the proposed citywide coverage, walking is presumably the chief linkage between the system and its patrons' ultimate trip ends. This linkage is quite appropriate to downtown, where SCAT service would compare favorably with use of an auto both in general convenience and in steps walked. In city settings outside of the CBD, the nonresidential trip ends are mainly at work places, public buildings, and stores—typically located on arterial streets and, therefore, apt to be reasonably near a SCAT station.

The residential linkage has particular importance, because transport studies consistently show that some 80 percent of all person trips begin or end at home. The citywide grid of SCAT routes, which frame cells $^3/_8$ to $^1/_2$ mile on a side in residential portions of the city, seeks to place service within an acceptable walk of most homes. Yet the walking linkage does have disadvantages, including the possibility of the tripmaker's being exposed to a downpour, walking on icy sidewalks, or being afoot after dark. Such disadvantages might be ameliorated by substituting vehicles for walking—for example, by a low-fare taxicab linkage incorporated with SCAT service. Unorthodox systems for vehicular linkage are also conceivable (battery-electric scooters stored at SCAT stations; driverless "golf carts" circulating continuously on minor streets) but are deemed not advantageous.

The most prominent approach to resolving the residential linkage problem appears to be the dual-mode idea. It may be exemplified by the generic "Urbmobile" concept advanced by Cornell Aeronautical Laboratory, Inc. (4). Dual-mode Urbmobiles could be driven on streets and highways, and could also operate on special trafficways at high speeds under driverless automatic control. Conceived as a kind of "drive-yourself rapid transit" combination, the system gives promise of door-to-door linkage plus the advantages of rail travel for long commuting trips.

Urbmobile may, on first impression, seem to be small car automatic transit having additionally the desired feature of excellent linkage. In comparison with the proposed SCAT ideas, however, Urbmobile is really so different that it constitutes quite another concept. The difference inheres in the Urbmobile itself, which by its size and performance is no less than a small automobile. It follows that the tramway for such conveyances must be so large as to raise serious doubt about the general feasibility of elevated Urbmobile facilities over arterial streets. In most situations, therefore, Urbmobile route planning would be confined to much the same right-of-way and construction practices that govern the planning of rapid transit lines. The Urbmobile route network is thus visualized as a relatively sparse one, perhaps comparable (or even congruent) with the metropolitan freeway network. Urbmobiles should serve the suburban commuter admirably, unless his work place is too far off-route to reach on foot and his driving linkage is vexed by parking or traffic troubles. Yet the system is unable, because its limited facilities so often must be augmented by driving, to promise extensive improvement in transport service for the one-third of the driving-age population not licensed to drive.

If Urbmobiles as such are of seemingly meager utility to many members of the existing transit market, nonetheless the dual-mode idea does warrant examination as a supplement to small car automatic transit. Any dual-mode conveyance adapted to SCAT facilities must be comparable in size with SCAT cars; that is, it could hardly be larger than a motorcycle encased in a slender shell. Such a conveyance, used both on streets and the SCAT trafficways, may be termed a "sub-Urbmobile." Its engineering—with the aim of compactness, low cost, and great reliability—must unite car switching and control functions with the vehicular requirements of steering, suspension, and independent motive power. The dual-mode version would surely weigh and cost more than a regular SCAT car. Maintenance expenses of sub-Urbmobiles would be compounded by their inherent complexity, reduced availability for servicing, and exposure to road abuses.

The incorporating of sub-Urbmobiles into a metropolitan SCAT system involves several requirements. The first is that sub-Urbmobiles must be completely compatible with the SCAT cars and facilities. Numerous ramps would have to be added for interchange between tramway and street. On the facilities, a sub-Urbmobile would function as a car. For example, instead of having to be parked, it could be left by the rider at any station to rejoin the fleet of anonymous cars (this assumes that the conveyances would not be individually owned). Sub-Urbmobiles could be driven from the SCAT facilities only by qualified patrons possessing a license in the form of a key or card specially designed so as to preclude unauthorized use. Were a station to lack a sub-Urbmobile, one could be called-in by any qualified patron. The converting of a sub-Urbmobile into a road vehicle would have it display the patron's license number in front and in back, both to facilitate his finding it when parked and to aid enforcement of traffic and parking regulations.

Several subsidiary considerations may be noted. If residential linkage is the chief purpose of sub-Urbmobiles, most of them, like family autos, would remain parked at homes overnight to be ready for linkage service in the morning. Many of these tiny vehicles could be blanketed-in by an overnight snow not affecting the SCAT car fleet. Of more significance, however, is the unavailability overnight of these dispersed sub-Urbmobiles for the routine testing and servicing given each of the SCAT cars in the fleet every few nights. Accordingly, the sub-Urbmobiles may be expected to cause more than their share of blockages on SCAT facilities. Finally, there is an obvious need for supervision of the sub-Urbmobilies. Their movements through any ramp would be reported automatically to a recording center to establish patrons' accountability both for possession of the conveyances and for their off-system mileage and time.

The major uncertainty about sub-Urbmobiles stems from the risk associated with their diminutive size, which poses a serious liability question for the agency furnishing them. There is no reason to suppose that driving a small and vulnerable sub-Urbmobile in present-day traffic would demand any less skill, judgment, and responsibility than would driving an auto. Therefore, a regular driver's license would probably be a requisite to qualify for a sub-Urbmobile user card. It follows that the citywide network would still be needed if SCAT is to give adequate coverage for persons requiring transit service. Also, the redundant capacity of this relatively close-meshed network would help to alleviate the more frequent blockages due to the use of sub-Urbmobiles on SCAT mainlines.

The prospects for the citywide use of sub-Urbmobiles appear to be poor, owing to their frailty relative to other street vehicles. Yet the very vulnerability of the sub-Urbmobiles points to a possible role for them where the SCAT system is weakest: in linking suburban homes with SCAT facilities confined generally to a few highways. In the suburban setting the usual clear distinction between road types should afford good opportunity for enforcing a strict prohibition on the use of sub-Urbmobiles beyond the comparative safety of subdivision streets. With this prohibition, backed by measures to assure traffic safety in subdivisions, their streets should be usable by sub-Urbmobiles with minimal risk. Such conditions could permit a policy of authorizing even responsible youngsters to drive the conveyances on local streets between home and the SCAT ramps at the subdivision entrances. Those would be the only mode-changing ramps in an installation, so long as prevailing traffic hazards were considered to bar the street use of sub-Urbmobiles elsewhere.

CONCLUSION

This paper has discussed an advanced transit concept based on a myriad of driverless cars able to range widely over their own exclusive facilities. Small car automatic transit, or SCAT, seems especially applicable to the middle-sized metropolis. The SCAT facilities (perhaps only modest beamways over the street) would form a network coinciding generally with the more traveled thoroughfares: most downtown streets, many of the arterials in the rest of the city, and suburban highways. The desirable qualities of small car automatic transit service as it is conceived here derive from the extensiveness of the network, combined with automation assuring safe push-button transport at all times.

The new mode should be beneficial both to people as tripmakers and to the urban environment more generally. In the middle-sized metropolis, SCAT would represent a vast improvement for virtually all users of present-day transit, for some persons now involved in pool-riding arrangements, and for the few individuals to whom driving or parking is a daily burden. To the extent that SCAT reduced dependence on automobiles, it would contribute to abating the environmental pollution and hazards due to vehicular traffic (and easing the competition for driving and parking space). System safety would have to be manifestly excellent, of course, if the constructing of a full SCAT installation were ever to be undertaken.

In the course of time, small car automatic transit might become an ecological imperative. Under present conditions, however, it may be regarded merely as a worthwhile alternative to the automobile, but not as its replacement. For the proposed mode system does not, to be sure, quite measure up to one's own auto. SCAT patrons would experience the inconvenience of numerous one-way routes, the lack of facilities for taking rides out in the less developed countryside, and difficulty in moving items like a carton of groceries so readily carried in an auto. A major fault of the system as proposed would be its inability (with rare exceptions) to convey anyone to or from his own door, with the corollary of time-consuming walking on many trips.

Door-to-door transport might be offered by modifying the SCAT system to accommodate dual-mode conveyances which would run driverless on its facilities, but could also be driven on roads. The attractiveness of this improved linking of homes with the network would, it turns out, be attended by considerable expense and complexity, aggravated by the critical vulnerability of such tiny conveyances while operating in street traffic. By limiting their road use strictly to local streets within residential subdivisions, possibly even persons too young to operate autos might be authorized to drive the little vehicles locally from home to the SCAT facility nearby. If an extensive SCAT network were combined in this way with dual-mode conveyances for suburban residential linkage, the majority of persons could have access to virtually all the important places in the metropolis without possessing an auto or regular driver's license. An arrangement like this may be the closest approach possible to a mobility breakthrough without putting everyone behind the controls of an automobile regardless of competence.

Should small car automatic transit (even without conveyances) eventually become feasible, it would be a factor in metropolitan planning. Though the applicability of existing modal-split models to forecasting the patronage of this innovation is questionable, there is little doubt that a SCAT network in proximity to 100,000 homes would have more effect on traffic conditions than any rapid transit line, however fast. Thus a metropolis thwarted now in the quest for rapid transit actually may be retaining an option to gain much more transport service later for a comparable investment. It also follows that a reappraisal of highway planning may be warranted with respect to the central portions of the metropolis, which so often present the most severe difficulties to transport planners and engineers.

The CBD would surely be affected by a metropolitan SCAT installation. It would improve the efficiency of the center by greatly facilitating local circulation there. This feature, however, would permit new development to spread beyond the walking limit that has tended to preserve a compact downtown core; financially marginal parking facilities would become liable to conversion to more productive use. At the suburban fringe, small car automatic transit could give an impetus to the cluster pattern of development, which appears singularly compatible with the new mode both economically and aesthetically.

Before SCAT could become a salient factor in the metropolis, formidable problems must be mastered. Design of the car-and-track subsystem presents difficult engineering questions. Network operation at even the proposed capacities and speeds demands the perfecting of extremely reliable controls. The importance of achieving the lowest possible unit costs for completed facilities cannot be overstated. If problems of a technical nature can be solved, difficulties of a broader nature such as vandalism must also be faced. In all likelihood, the acceptability of elevated facilities must be established by thorough legal research and the temporary installing of full-scale tramway models along streets. Finally, if the development and promotion of small car automatic transit should become a serious venture, care must be taken to preserve operational compatibility among installations that, by growth, might eventually interchange traffic.

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Supra-Car

GEORGE HAIKALIS, Tri-State Transportation Commission

Pneumatic tired, individually steered, self-propelled vehicles have been the backbone of the nation's passenger transportation system for over 50 years. Every expectation is that this dominant role will continue for many years into the future.

The concept and design of a successor to the automobile has remained elusive. Innovation seems to be aimed at incremental improvements to the auto, or mass transit devices that are intended to divert auto travelers to transit.

Outlined herein is a design for a total successor to the automobile. Auto driving would be confined to remote rural areas and race tracks, and, in miniature form, at carnivals and amusement parks. Nearly all truck movements would also be accommodated by the "System"; as would all mass transit travel other than longer-distance air travel.

SYSTEM DESIGN

No dimensions are given on Figures 1 through 5 illustrating the system concept. Detailed engineering studies would be needed to select the appropriate design parameters. However a few design characteristics might be noted.

Cars

Most automobiles operated in the U.S. can accommodate six passengers though rarely are they used to this capacity. The cars in the proposed system probably need not hold more than 4 passengers (two couples); since no driving skill is required and cars would be readily available. A very comfortable 4-seater would measure 4 ft wide and 6 ft long, with pairs of seats facing each other. A 6 ft height would allow walk-in convenience and speed. Passenger payload need not exceed 1000 lb, and the car itself could be held down to another 1000 lb or less.

The optimal design selected for the passenger car would also accommodate most freight now moved in urban areas by truck. Only large structural steel members, outsized pieces of furniture or lumber, and heavy machinery, etc., would not meet the size or weight limitations of the passenger car. Small unit sized goods, now grouped into larger packages, could be regrouped to fit the system car. Though in some cases a great many more trips would be required, goods movement would occur without attendants except for loading and unloading. Passenger seats would fold out of the way and for certain types of goods preloaded pads would be inserted. In time, many outsized goods would be redesigned to fit the system. For example, fire fighting apparatus could be packaged in subassemblies that would converge at the site of a fire.

Guideway

The configuration of the guideway and the undercarriage of the cars illustrated in the figures is an example of a possible design.

Column spacing is assumed to be about every 20 ft. This would give access to the ground comparable to motor vehicular access. While every column could serve as a

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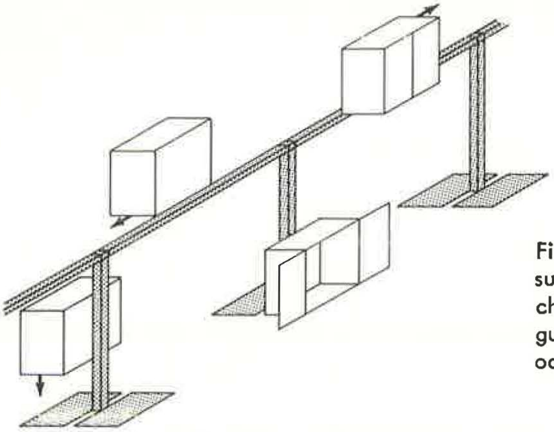
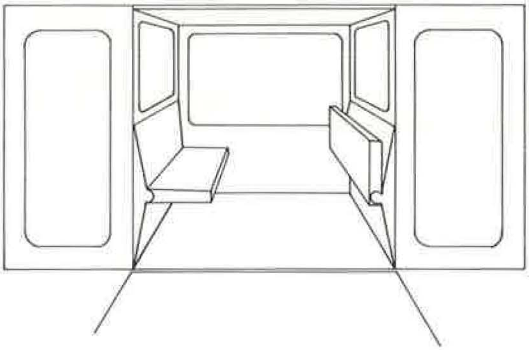


Figure 1. Basic system design. Elevated guideways supported by frequently spaced columns provide the channels of flow. Individual cars track along the guideway and up and down columns. Access to cars occurs at ground level, at the base of a column.



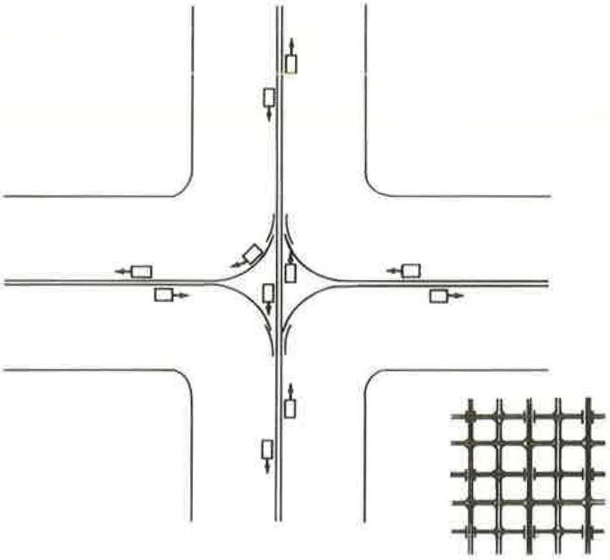


Figure 2. Route location. The guideways would be constructed along all existing streets. Cars would be routed through the system from column of origin to column of destination. Cars would move as fast as they could subject to traffic conditions. Express or bypass guideways would be needed through areas of concentrated traffic generation.

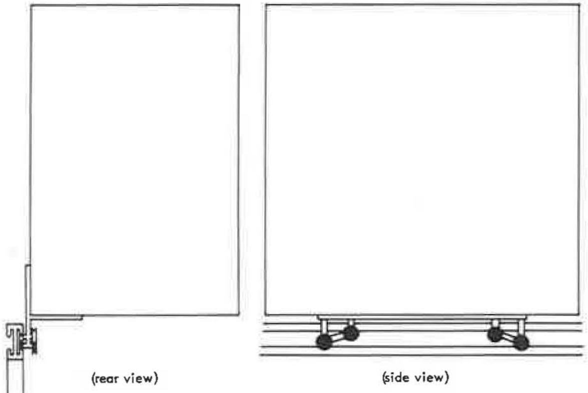


Figure 3. Car and guideway configuration. This suggested design minimizes guideway beam cross section at the expense of a more complicated car undercarriage. The intent is to permit a more extensive and less obtrusive network in order to reduce initial investment.

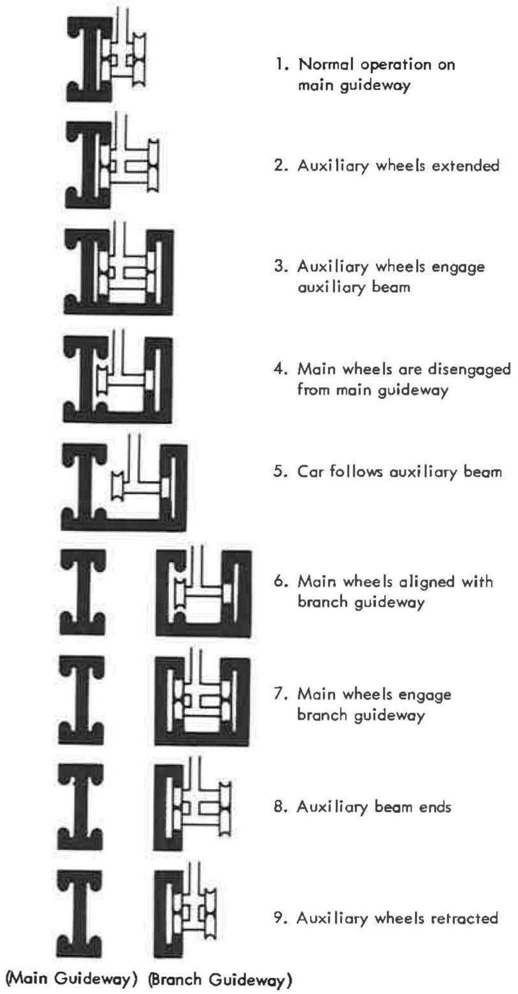


Figure 4. Switching sequence. The track structure remains inert and the switching maneuver is accomplished by the car engaging the branch beam and disengaging itself from the mainline.

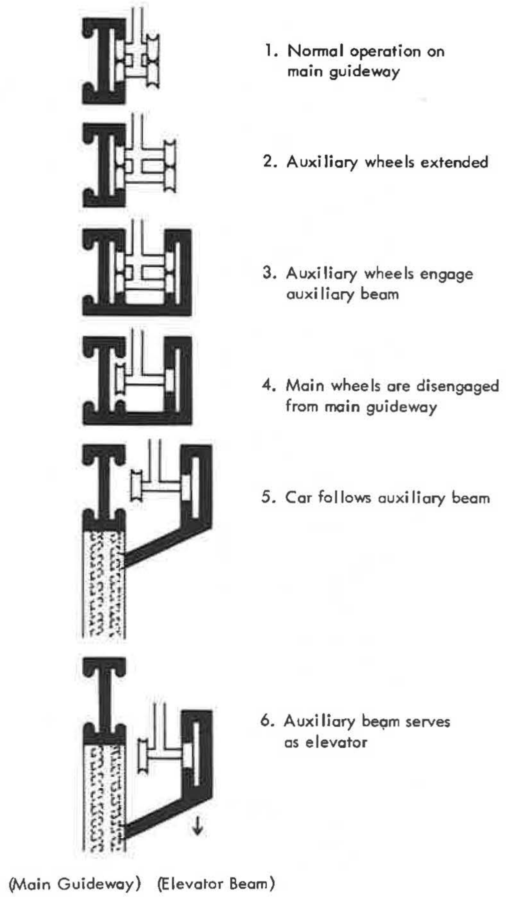


Figure 5. Guideway to column transition. The transition from horizontal to vertical motion is similar to the switching maneuver. The auxiliary beam, engaged, becomes the elevator lowering the car to ground level.

loading point, in low-density areas only selected columns would be fitted with the required appurtenances. For the design shown in Figure 5 columns serving as loading points would require elevator beams. Cars would be lowered to the surface as in Figure 1. To protect pedestrians the landing pads would probably have to be enclosed, and if sliding doors are used on the cars, door pockets would also be required. One possible elevator mechanism is suggested in Figure 5. Columns would include a threaded channel and cars would raise and lower themselves by mechanically coupling their propulsion system to a screw fitted to the thread. Limitation on guideway curves and grades would be no greater than for motor vehicular ways.

Control and Propulsion System

The functions of the control and propulsion system can be readily specified. Their detailed design, however, represents one of the most difficult tasks in achieving the proposed transportation system. Propulsion for the cars would most likely be electric. While battery or fuel cell sources of power may eventually be available, power conductors fitted to the guideway would provide an inexpensive and dependable source. Perhaps the flow of current and change in impedance in the propulsion power circuitry could form the basis of the vehicle detection and intervehicle coordination functions of the control system. The advent of microelectronics and initial experiments with automatic motor vehicular operation suggest that the required system may be readily attainable. Fare collection, destination selection, route selection, and empty car flow are other significant elements of the control system which must be detailed. The division of these control tasks between cars and control centers would be a major design problem.

Capacity and Speed

Two elements of traffic flow capability may be considered: terminal capacity and line capacity. In the suggested design each column may serve as two loading points (Fig. 1). Assuming a two-way guideway along each street, 20-ft column spacing, and 25 miles of street for an intensively developed square mile of land, 12,500 loading points would be available per square mile. If the column elevator performance could equal that of modern automatic elevators, car loadings as frequently as two per minute could be achieved per column channel. Boarding capacity of the system would then approach 1,500,000 car origins per hour per square mile, or 6,000,000 seat origins per hour per square mile; well beyond the requirements of the most intensively developed square mile on earth—the Grand Central area of Manhattan.

The flow capability of the guideway lines and junctions will depend on the degree of sophistication of the control system. A minimum goal might be the attainment of flow rates comparable to the highest observed motor vehicular rates—2100 vehicles per hour per lane. Higher capacity would be obtained by increasing the number of channels or by raising the flow rate through more elaborate controls. Channel proliferation need not be too frightening because of the compactness of the guideway and cars. The six-lane Long Island Expressway, for example, carries, at most, 6300 vehicles per hour per direction. The same cross-sectional area could accommodate 32 guideway lanes with a capability of 33,600 cars per hour per direction.

No particular guideway speed is specified by the nature of the proposed design concept. Top speed would be a function of the structural requirements, propulsion and control system capability, aerodynamic resistance, wind forces, and economic considerations. Probably speeds over 60 mph would increase costs to the point of diminishing return. Perhaps the vehicles might be designed for a 100 to 120-mph capability which would be used only on specially designed long-distance guideways. Speed of travel on urban guideways would depend upon the degree of traffic interference, and restrictive curves and grades. No real need for a uniform speed seems to exist. From a control standpoint uniformity in speed-change and response time is important.

SYSTEM ADVANTAGES

A very effective system of individual vehicular transportation exists throughout the United States today. Why should a new system be developed that can do an equivalent job, but requiring an elaborate mechanical and electronic structure?

Certain inherent weaknesses are built into the present motor-vehicular system: Driver controlled vehicles, through remarkably easy and safe to operate, still result in over 50,000 fatalities a year on the nation's highways. Despite the ubiquity of auto ownership, a very substantial though declining number of travelers continue to use mass transit services in major urban areas across the country; in fact, investment in new mass-transit facilities seems to be accelerating. Just over half of the nation's population is licensed to operate motor vehicles; the remainder must depend on friends and relatives or mass transit. Highway construction in urban areas has, in many cases, resulted in painful relocation of established residences and businesses. And, finally, the ever-increasing density of internal combustion exhaust contaminants released into the atmosphere of major cities poses an undefinable but worrisome threat.

The proposed transportation system offers the possibility of diminishing or overcoming entirely these undesirable attributes of the existing technology of travel. Significant improvements in the quality of transportation service might also result. Travel speed could be greater than at present; driverless travel would be more relaxing and would release driver-time for more rewarding activities. Mass-transit travelers would enjoy the individualized transportation now available only to motorists.

Intriguing urban design possibilities can be envisioned with the removal of motor vehicular traffic from the streets. While some provision would have to be made for the infrequent movement of outsized loads, street space, constituting 20 to 25 percent of urban land, could be released for other uses. In densely developed areas this extra elbow room would be of significant value. For example, enclosed shopping malls would be possible in older business centers. Vast off-street parking areas in outlying areas would no longer be needed.

Far-reaching changes in land development and society in general, on a regional scale, might occur. The centers of large regions would lose their unique advantage of accessibility attributable to their mass transit systems. But perhaps more important they would lose their extreme disadvantage with respect to parking cost and congestion. Another effect would be the possibility of out-migration from the region's center of those persons who have lived there because of their inability to own or operate automobiles. Another effect would be the capability of transporting the very young between any residence and any school in the region. And, finally, the handicapped and the sick would have improved transportation permitting better access to jobs and to medical care.

The most significant aspect of the system's relative advantage or disadvantage is cost. Unfortunately, very little can be specified about the cost of the proposed system. Some aspects of the Tri-State Region's existing highway and mass transit costs might provide a source of comparison. Close to 20 percent of the Region's economic activity is devoted to the local transportation of persons and goods by auto, truck, taxi, and mass transit. Around $5 billion a year is spent keeping the Region's nearly 5,000,000 automobiles garaged, fueled, repaired, insured, and washed. At least $2.5 billion a year more is needed to operate a half-million trucks making local deliveries. About half a billion dollars a year is spent on taxi and mass transportation in the Region. Eight hundred thousand new cars are purchased each year in the Tri-State Region; about 1200 miles of new local streets are added annually to the region's 45,000-mile road network, and 100,000 parking garages are constructed each year in conjunction with new residential dwellings.

A 50,000-mile network of guideways and perhaps 3,000,000 cars might do the work of the existing Tri-State urban transportation system. If the proposed, heavily capital-oriented system could operate at a $1,000,000,000 annual cost, then annual savings of $7,000,000,000 would occur. Capitalized, this savings would mean an investment of $70,000,000,000. If the investment were split evenly between guideway and cars unit costs could be as great as $700,000 per mile of guideway, and $12,000 per car. There is a good possibility that capital cost could be considerably less than these maximums. Concerted engineering design and analysis effort is needed to establish the system's credibility.

DEVELOPMENT PROGRAM

The potential market for the proposed system is vast—as much as a trillion dollars would be needed to construct a nationwide network. If the system were a commercial success there would seem to be little difficulty in obtaining private investment. The degree to which private capital might be available for exploration and development of the concept is unknown. The extent of investment needed to satisfactorily develop the concept into a "working" system would be great.

Detroit beware!

Orientation and Transit Systems

PETER CHERMAYEFF, Cambridge Seven Associates, Inc.

•AIRPORTS have become transportation's most conspicuous failure in terms of systems design. Speed, efficiency, and comfort in the air get better, while impedance, chaos, and frustration on the ground get worse.

To a large extent, of course, the problem is caused by excessive dispersal of facilities, and by obsolete or nonexistent technology for essential functions, such as baggage handling, ticketing, transfer to other airlines, or transfer to various ground transportation modes.

The problem is also one of confusing or nonexistent information, on which all other functions depend. Without clear and immediate information, the airline passenger who could possibly transfer quickly and easily to his car or to rapid transit remains confused and frustrated. In effect, there is a clarity gap—a gap caused by much more than poor signs.

In a less dramatic way, a similar gap has been developing in urban mass transit. Because we have given them so much of our attention, new levels of vehicle technology are available, although still waiting to be applied. But there has been very little attention given to those elements of a more commonplace nature, not requiring any sophisticated technology, that are nevertheless essential to the success of urban transit in functioning as a system.

Ironically, many of these elements are also those that can be applied with relative ease and low cost to existing urban transportation networks. Perhaps they will begin to receive a higher priority if their purposes and implications can be better understood.

This paper describes briefly passenger orientation as a criterion of transit planning and design having a very broad impact on the quality of the passenger's experience. In some instances it is a key to turning a nightmare that we tolerate into a pleasure we can choose.

Orientation is a criterion and a yardstick that to a large extent can be used as a substitute for the confusing considerations of aesthetics. "Environmental quality," often stated as a general goal, is nebulous at best. Very few people can agree on what such a term means. To many it means nonessential frills. Agreement that vehicles and stations should be "attractive" or "well-designed" does not, in most cases, amount to more than lip service or a protestation of virtuous intentions. A more precise language is needed.

When alternate visual solutions can be evaluated only in vague aesthetic terms, a decision is often either arbitrary (a matter of individual tastes) or based exclusively on lower cost. In transit, the result can be a kind of salad of uncoordinated parts, filled with unnecessary compromises. When environmental design, like other areas, begins to have precise performance requirements, then meaningful cost-benefit analyses become possible for each decision.

The advantage of orientation as a general guiding criterion of transit design is that it applies to almost all perceived parts of a system, and becomes a useful tool in tying them together in a coherent whole. It also can be demonstrated, as is being done in Boston, that the accumulation of strong, well-coordinated parts produces, indirectly, a very pleasant environment. No special effort is required for pure aesthetics, such as decorative nonfunctional additions of colored tile and the like. The logic and strength of an orientation system takes care of aesthetics by itself, when carried out properly.

Paper sponsored by Committee on Future Concepts and presented at the 47th Annual Meeting.

A concern for orientation and information is far more than a call for graphics. It is a matter of total environment, including urban design and architecture.

SYSTEM IDENTIFICATION

Many existing transit systems suffer from lack of visible reminders that they even exist. The daily commuter who is forced to use transit needs no help in this regard, but the stranger, for example, may find himself unnecessarily walking miles or hunting for a taxi only because he did not know that a subway line was there. He did not see the entrance.

Identification of the system as a whole, therefore, becomes the first orientation function, and a symbol becomes a first step in the design process. A symbol for a transportation system should solve many problems. It should be recognizable at a considerable distance in the competitive (often visually noisy) cityscape, it should be legible at any size, and usable in many different forms. It should make sense at a glance to the stranger regardless of his language. Four symbols that succeed in these terms are those for the Montreal Metro, Stockholm Tunel-Banan, London Underground, and Hamburg U-Bahn-Netz.

A transit symbol does not need to be original or unique. Boston's, for example, a T in a circle, is similar to Stockholm's and was chosen because it was clearly appropriate. It solves the above problems, and it can also be used in its own right as a word. One can ride the T. It means "transit" or "transportation" or "tunnel" or "tube" or many other associated words. And since many of these same words begin with T in most European languages, it could successfully be used in all cities as an international standard symbol.

Applied in the streetscape to identify a station, the symbol becomes a large and simple two-sided backlit sign, standing on the sidewalk, or bracketed off walls, and placed in enough locations to catch the eye of pedestrians approaching from all directions. At a normal street intersection two signs are sufficient, mounted at 90 degrees to each other and located at diagonally opposite corners.

In the case of bus stops, the use of the symbol at the top of a smaller metal sign, mounted perpendicular to the street, makes the location of the bus stop visible to pedestrians and drivers at distances of several blocks. In many cities, this simple device makes all the difference in telling a stranger or infrequent rider that on a given street, bus service exists.

ROUTE STRUCTURE

Disorientation in a subway system can be more than frustrating; it can be frightening. Many people have a basic disinclination to go underground—a fear of getting lost or trapped in a maze of unknowns. Many simply will not make a trip by subway if they have no mental image of their route in advance. A mental image takes more than familiarity. Even long-time residents of large cities are often unable to visualize the shape of their city simply because their city's maps lack visible structure.

If transit lines are thought of as a kind of skeleton, they can be used to increase the legibility of an entire city. A transit map can then become not only a guide to a transit system, but a guide to perceiving or visualizing the shape of the city itself.

Several types of maps emerge as precise orientation functions are broken down. The first of these is a kind of diagram, simplifying and reflecting the actual shape and scale of the city and eliminating all nonessential information. This allows the map to be read at a glance in passing. Major routes, stops, and interchanges are main elements, with the inclusion of landmarks, such as bridges, or topographical features, such as water areas, only if necessary for the map reader to quickly locate himself. This latter device, for example, is necessary for New York's large system, but not necessary for Boston's smaller one.

Color coding plays a major role in articulating and giving strong identity to each transit line. In the Boston system, because there are only four lines, color coding was further reinforced by giving the lines the names of their colors: Green Line, Orange Line, Blue Line, and Red Line.

Figure 1. Remodeled entrances to Arlington Station, showing signs for system, line and station identification.

There are many important applications of color coding to complement diagrammatic maps. One of these is the use of backlit color-coded entrance signs mounted directly over each entrance point. The pedestrian who sees, for example, the color green on signs of this type knows without thinking that the Green Line is running underneath. He begins to develop an unconscious awareness of the line's route and begins to relate it to the specific street or urban environment above grade.

Another important application of the color coding that reinforces public visualization of the line structure is a wall band running the full length of each station platform carrying the station name. The band of color reminds the passenger as he passes each station that he is riding, for example, on the Green Line. This simple function, however obvious it may seem, is often ignored in existing subways. The band is a strong element in the visual environment of the station, and has the secondary function of neatly framing other informational elements that are needed on platform walls.

Another device that further articulates the line structure is letter coding, which gives strong identity to each branch of the main transit lines. The letters must occur on maps as well as on the fronts and sides of the vehicles themselves.

STOP SEQUENCE

Since transit lines are linear in nature, the passenger wants to be constantly aware of the exact sequence of stops along his route, so as to have a sense of time and distance.

Figure 2. Remodeled mezzanine, showing map units outside fare collection, new turnstiles with new orienting nose shape, and accent lighting.

Figure 3. Typical map units at a mezzanine, including diagrammatic map of rapid-transit lines, letter coding for branches of a line, and a neighborhood map.

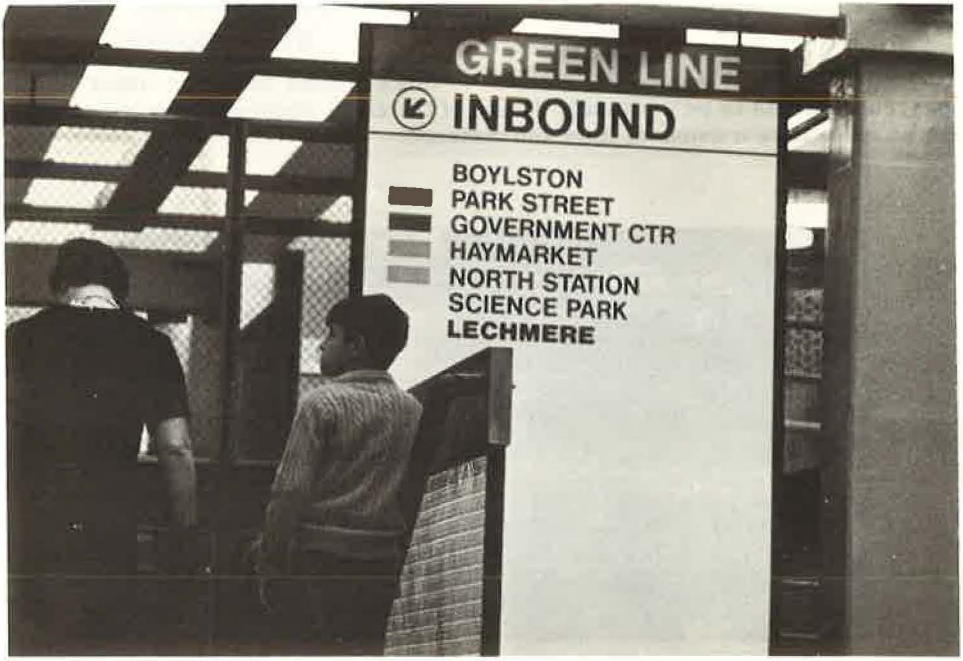


Figure 4. Typical sign at a decision point (top of stair) giving line name, platform direction (inbound), sequence of stops and identifying transfer stations to other lines (color bars).

Figure 5. Segment of side wall at remodeled platform, showing upper and lower color-coded name bands, white directional sign band, map and typical photomural.

Figure 6. Remodeled station platform, showing walls facing the trains, with name bands, directional signs and photomurals, and showing center track area, facing the waiting passenger, with advertising posters.

Strip maps within the vehicles should be so located that any passenger can easily see them and know how many stops remain on his trip. These maps must relate very carefully to the main map in terms of color coding, designation of transfer points and letter coding of branch lines.

Lists of stops are also needed within the stations in conjunction with the diagrammatic line maps, so that a passenger can quickly spot his destination and the sequence required to reach it. The rapid-transit line maps and these sequential lists of stops must be located together at all mezzanines and lobbies, in full view from all approaches, and on both sides of fare collection, so that reference can be made to them both before and after the passenger has decided to enter the system. When other maps are also included, it can readily be seen that a great deal of wall space is required for this information function.

In the Boston system, up to 20 feet of map space is called for on both sides of fare collection, and the impact in architectural terms is strong. In some cases, walls have to be added or modified to accommodate these units. A secondary result of this is that mezzanine and lobby spaces require little or no further wall decoration in order to be visually colorful and pleasant.

VEHICLE DIRECTION

Even with the help of maps, infrequent subway riders often find themselves down at the platform waiting for a train wondering if they are at the wrong platform, or getting off a train wondering which way to exit. A passenger underground is easily disoriented by a full 180 deg reversal of direction.

Boston's transit system is radial. The rapid-transit lines move in and out of the downtown center. Directional orientation at almost every station platform in Boston therefore becomes a simple matter of differentiating inbound from outbound.

One obvious device for this function is to use the words "inbound" and "outbound" on the appropriate sides of the station. This is done in Boston, But in addition, the end walls of the platform spaces are color coded, using vertical alternating stripes: blue/green for outbound and red/orange for inbound. This system allows any passenger at any point in the platform area, whether arriving or departing, to glance down the length of the platform and be immediately oriented in terms of direction.

In other cities, variations of this device would suit different conditions. In New York, for example, an inbound-outbound coding could apply to the outer boroughs, and a north-south-east-west coding could apply to the more grid-like structure of the lines in Manhattan. Typographic symbols can do this job as effectively as color, and where appropriate, in combination with color.

A secondary result of this particular coding device is that the platform spaces are visually terminated with strong accents, giving considerable liveliness to the space and again through a meaningful rather than arbitrary element.

BUS ROUTES

We have discussed several orientation aspects of rapid transit, but their connection and integration with numerous complex bus routes is in most large cities an important part of the orientation problem. Many cities, of course, also do not have rapid-transit systems at all, and rely almost exclusively on buses.

The most obvious method of providing clear bus route orientation (in addition to the prominent display of the system's symbol on bus stop signs) is to use a number coding, assigning numbers to each route. Most transportation systems, however, are weak in displaying these numbers in a way that encourages the public, particularly infrequent passengers and strangers, to become familiar with them.

In the Boston system, each bus route number is prominently displayed on backlit roller curtains at the front and side of the bus, in combination with the destination. Lettering is white on black background. Those routes that terminate at rapid-transit stations have background color corresponding with the color of the the rapid-transit line with which the bus connects. In addition to this so-called primary reading, a secondary reading is included at the right side of the sign, if the bus route passes one rapid-transit line on the way to another. The background color of this secondary reading corresponds to the second rapid-transit line.

Bus stop signs at street corners and stations must also carry the same route information. In addition to the system symbol, which identifies the bus stop location at a distance, route labels should be included on these signs using the same route numbers and destinations, and their corresponding background colors.

Finally, any system needs a map that shows in detail and to scale the city streets and the entire network of bus routes and their connection to rapid transit, if any, or other modes. Boston's system map includes private suburban bus carriers, railroads, and major highway route numbers, and identifies all streets and many landmarks. This detailed map becomes another major map unit for cluster use at frequent intervals on station walls, in addition to its normal function as a paper folded map for wide distribution from booths, vehicles, and through the mail.

ROUTES WITHIN STATIONS

Within stations, particularly those underground, directional signs become a critical part of the orientation system. Complex stations, such as those in downtown Boston, Chicago, or Manhattan, are often bewildering labyrinths of passageways and stairs.

A clear signing system can best be developed following a sequential analysis of each type of passenger route. For example, the entering passenger requires station identity signs and color-coded entrance signs at street level, and as he passes through fare collection, he needs clear directional information regarding his chosen route at each decision point that he encounters, such as at branches of passageways and stairs. Along his route, he needs reassurance at frequent intervals that he has made the right decision, and on arrival at the departure platform he needs reassurance that he has arrived at the right platform.

The exiting or transferring passenger also requires directional information at each decision point along his route from his vehicle to the street or from his vehicle to another vehicle. His sequence begins as he disembarks from the train, and his first need is to see the station name. The continuous color-coded band should include the station name printed in white and at close intervals so that it is visible from all points in the train, regardless of columns or other obstructions. In the Boston system, a second identical name band is added approximately 18 inches from the floor on those platform walls that are so close to the train that the upper name band is not comfortably visible to standing passengers.

The exiting or transferring passenger's second orientation need is to locate the escalator, stair, or passageway that leads to his exit or transfer point. A white band, directly under the upper colored name band, can be used for directional signs printed in black. When repeated at close intervals, these signs are immediately visible to the passenger, regardless of the particular door position at which he disembarks.

Finally, directional signs leading the passenger to his exit or transfer point are needed at each decision point along his route. The exiting or transferring passenger also needs reassurance at frequent intervals, particularly if he has a long way to go.

These signs are not minor items to be added as afterthoughts. To serve their purpose, these elements must be visually strong and frequent, and as a result they play a major role in the animation of an underground environment.

It should also be recognized, and it cannot be overstressed, that better stations require fewer signs. Architecture that has concerned itself with orientation from the outset requires less graphic assistance.

Clear orientation within stations is also assisted in important ways by the design and location of equipment. Lighting fixtures are the most important example and should be designed to provide for more than a minimum number of equally distributed footcandles. Areas that should be accented with very high brightness (in contrast to other areas of medium brightness) include stairs, intersections of passageways, and fare collection channels. In effect, this kind of lighting draws the passenger's attention to the critical circulation channels along his route.

Another important orientation function of lighting, often ignored, is to bring out the shape and scale of architectural spaces without glare. Indirect lighting, thrown upwards into concrete coffers, or vaulted ceilings, makes these spaces visible and memorable, assisting the passenger to know where he is.

Other items of equipment affecting orientation are turnstiles and exit gates. The token-operated turnstiles of the Boston system have been redesigned with a new angled nose, replacing the earlier symmetrical round nose, so as to tell the passenger which side of the machine to pass. The standard exit gate, with its inevitable rows of unfriendly meshing teeth, was redesigned with massive black teeth on one side and light stainless teeth on the other. The result, again, is clearer orientation, since the passenger knows at a glance which way the mechanism rotates. Movement through it becomes quicker and safer.

CONTROL OF CONFLICTING ELEMENTS

Transit stations and vehicles have for many years suffered from an accumulation of clutter, a major factor in disorientation. Examples include exposed conduits and miscellaneous conspicuous and disorganized signs, fixtures, hardware and changes of materials. The solution to this problem is maximum simplicity and order and the elimination of the unnecessary.

An often unrecognized example of unnecessary conflict is the use of color for arbitrary purposes or for purposes not coordinated with a color-coding system. The result of this can be to undermine color coding and create confusion. Vehicle painting, for instance, should avoid use of any colors that are also used to signify transit lines on maps. The Boston solution was to unite the diverse fleet of vehicles with a common color scheme, using neutrals—grey and white, metal and white, and all metal—and accenting the doors with yellow. This use of yellow conflicts with no other uses of yellow in the system and serves an orientation function, particularly on crowded train platforms where the departing passenger finds himself looking for the door.

The most powerful single offender has been revenue advertising. In most systems in the United States, posters of diverse sizes and shapes have been indiscriminantly installed in locations where information and orderliness are most important. In some transit systems, very large posters have not only replaced information, but have overpowered, even obliterated, architectural spaces. The development of national standards for the control of advertising has become essential.

Our study of this problem led first of all to one basic guiding principle, that advertising makes a positive contribution to the waiting passenger who does not need information, and a negative contribution elsewhere. Since the waiting passinger is also the most thoroughly exposed, the advertiser gains as well from concentrating on him.

In vehicles, the exclusive recommended location for posters is above the windows in the standard continuous strip, reserving spaces adjacent to doors for maps and schedules. In stations, the exclusive recommended location for posters is across the tracks from the waiting passenger. In those stations with divided platforms, this calls for advertising frames in the center, between tracks, and in the case of island platforms it calls for frames located on outer walls.

The important point is that the waiting passenger no longer needs information. He is killing time, and posters therefore become a pleasure, a changing exhibition. The disembarking passenger, on the other hand, does not wait and does need information. Wall space opposite the windows and doors of arriving vehicles should therefore be reserved exclusively for purposes serving orientation.

SPATIAL CLARITY

Orientation results primarily from systems of graphics and hardware. But the most significant contribution to orientation is a clearly organized space. In vehicles this calls for visual openness, within the vehicle and to the outside. It calls for an orderly interior shell, simplicity of layout, and unobstructed circulation at doors.

In stations it often calls for generous volume with high ceilings so that everything is visible, and it always calls for a minimum number of turns, bottlenecks and changes of direction at stairs, passageways, platforms, lobbies or any other circulation spaces. When all functions can occur within large single spaces, or adjacent spaces that visually overlap, orientation is at its best. The Montreal system is the finest proof of this principle to date, since it has many stations with large spaces that are so visually clear, free of obstructions (such as columns) and well organized that almost no signs or other orientation devices seem necessary.

In fact, optimum orientation to and within a transit system will only be achieved when such spaces are combined with a strong coordinated system of signs, lighting, and other supporting elements.

Optimum orientation in underground stations also requires the penetration, wherever possible, of daylight. In some cases, the introduction of relatively small skylights can produce a refreshing sense of station position and an orienting relationship to the outside world, including an awareness of climate conditions and time of day.

SENSE OF PLACE

The areas described so far are concerned with the function of orientation on a system-wide basis. Within the overall system, the criterion of orientation is also concerned with the individual character of each station. It is the assertion of individual character, of place, that in fact gives orientation its greatest thrust by using a disciplined overall system as a foil for meaningful variety.

Cities, by definition, are diversified, filled with idiosyncrasies, with events and places and experiences from which each person assimilates his own image of his city. By being exposed to the full variety of places, while traveling through the city, the transit passenger has an opportunity to see his environment with fresh and appreciating eyes. Deprived of any exposure to it, he can only become indifferent.

In Boston, we introduced a concept of photomurals, located at frequent intervals along the full length of platform walls and directly opposite the windows of the trains. The subjects are entirely based on the surroundings of the station, and therefore become an instantly recognizable expression of the neighborhood. At a glance, the passenger knows where he is and whether he gets out of the train or not.

Another element containing more detailed information is a neighborhood map, showing the street surrounding the station and locating points of interest, street numbers, and bus stops. These maps, when clustered with other maps, further increase the already substantial dimension of map space which is required at station platforms. The maps should be clustered as information units and then be interspersed with photomurals along the full length of the platform. All units should have the same height, and all should be framed top and bottom by the continuous color-coded station name bands. The result is a very orderly and meaningful wall system that applies to all station conditions with flexibility and consistency.

In addition to photomurals and neighborhood maps, the most powerful means of giving individual identity to a station is to open it spatially to its surroundings. A large skylight or unsheltered opening can give a broad view from a platform to the street above, including glimpses of people, buildings and trees. Station spaces and adjacent spaces should not only overlap visually, wherever possible they should combine.

Orientation will be complete and optimum when new stations are fully integrated with their surrounding activities. For example, a station that is spatially part of a larger complex, by being part of a concourse or a plaza containing shops, theaters, restaurants, and sitting places, will not only absorb the individual character of that "place," it will also become a "place" in itself, a center of human activity, a generator of social interchange.

In summary, transit has an extraordinary role to play in urban life, and to achieve its potential it must do more than move people more quickly and more cheaply to more places. It must close its clarity gap and become legible. By doing so, it can also, without the arbitrary application of "aesthetics," become a far more pleasant environment than it is now.

In the long run, when service and environmental quality get together, transit may be able to offer affluent America an alternative to the private car and thereby help enormously to make our cities livable.