Structured Approach to the Evaluation and Comparison of Alternative Transportation Plans

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The process of evaluating alternative transportation plans is examined in an attempt to provide an overall structure to the process. A set of questions that can be used to define the evaluation process are given. These questions consider such issues as the scope of the process, its interface with other activities such as model development or plan design, the actual process of evaluation, and the interpretation of evaluation results. Within this framework a multidimensional evaluation process is described. This process involves the careful analysis and distillation of information contained in an evaluation matrix through a series of steps aimed at identifying significant differences among alternatives. Procedures are suggested for eliminating criteria that are not relevant to a decision and for eliminating alternatives that are clearly inferior. Such a process allows for a more careful examination of the trade-offs among alternatives and the implications of the criteria used to measure plan performance.

The process of evaluation may be one of the most crucial phases in the selection of an alternative course of action that best meets a previously defined set of goals and objectives. The final choice of the appropriate plan should be not only a choice of the best plan, but also a choice that has been strengthened through careful interpretation and that has been tested and found significantly superior to the alternative plans.

While there have been extensive efforts in the past to accurately forecast future travel-demand conditions, environmental impacts, and other factors, the levels of effort to develop evaluation procedures have not been as extensive. These previous efforts (1, 2, 3) have concentrated on defining the overall process of evaluation and outlining some basic principles to be applied to the process. The major emphases have been on the roles of different interest groups in the evaluation, the use of a systematic approach, the importance of an iterative process, and the need to consider nonquantifiable factors in the evaluation. These efforts have provided a substantial framework on which evaluation can be based. However, when the process of evaluation as it is practiced in many transportation agencies is viewed, one finds that there is a substantial gap between what is actually done and what should be done. Too often the actual evaluation process is overly mechanical, poorly documented, and done without consideration of many of the principles discussed in the references above. Moreover, the techniques and procedures used vary considerably from agency to agency. There is a need to define in greater detail a more open, yet structured, process of evaluation as it can be performed under the constraints of a transportation agency. This paper presents an attempt to structure the evaluation process and to suggest methods whereby it can be accomplished.

The paper has two parts. In the first part, a series of questions have been prepared that can be used to define the overall scope of the evaluation process, its interface with other activities, the nature of the process, and the interpretation of evaluation results. The second part outlines a step-by-step procedure that can be used in a plan evaluation that attempts to clearly define the trade-offs among the alternative plans.

STRUCTURING THE EVALUATION PROCESS

Some basic questions must be addressed in order to structure a procedure for the evaluation of alternative land use and transportation plans. The questions are fairly general, and their purpose is to shape the sequence of steps that can be used for evaluation. (For the purposes of this paper, evaluation shall be defined fairly narrowly as the process of selecting the best plan from a given set of alternative plans according to a given set of objectives and criteria.) As will be illustrated by the set of questions, there are important links between evaluation and other phases of the planning process that must be carefully defined and analyzed.

Scope of the Evaluation Process

There is a need to define the scope of the evaluation process. The answers to the following questions may have a significant impact on the amount of time and effort that are necessary to perform an evaluation.

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1. What should be the area levels of the evaluation? A plan that is good for an overall region may be very poor for certain subareas and very good for others. Other plans may have different subregional impacts. If these subregional impacts are significant, there may be a need for evaluation at subregional levels.

2. Should the evaluation be conducted separately for different population subgroups? Since different population groups may be affected in different ways by the plans, there may be a need to examine the plans separately for each subgroup. What subgroups should be analyzed and how should such evaluations take place?

3. For what time periods should the evaluation take place? Since the plans may be implemented at different rates, should separate evaluations take place, for example, for 1980, 1990, or 2000?

4. What procedures should be used to answer questions 1 to 3? How does one determine what subareas, subgroups, and time periods to analyze?

Interface of Evaluation Process With Other Activities

The evaluation process has important interfaces with other activities such as the development and the analysis of the alternatives, and answers to several questions in this area are needed.

1. To what extent is it possible to return to the analysis or development of alternative phases of a planning effort during the evaluation phase? If new alternatives emerge during the evaluation process is it possible to return to these phases and iterate the process?

2. What potentials exist for making partial decisions at one time and other decisions at a later time when additional information is available?

3. How will alternative elements of a plan be combined? When one element is included in a plan, its presence may dictate that other elements also be included so that a workable system exists.

Evaluation Process

Other questions relate to the procedural steps that will take place during evaluation and to the methodology that will be employed.

1. What general method will be used to examine the evaluation matrix? Two basic methods can be used to examine an evaluation matrix. These are weighting techniques in which the information in the matrix is collapsed into single-number and multinumber techniques in which the matrix is kept intact as comparisons are made. Single-number techniques have some advantages but can also lead to difficulties if not used with extreme care. Some of these difficulties are the masking differences and trade-offs between alternatives, problems in assigning weights, dealing with intangibles, and mathematical inconsistencies. Multinumber techniques allow for a more careful analysis of the trade-offs between alternative plans but have not been used widely.

2. What rules can be used to combine or eliminate criteria? If all alternative plans perform equally well on certain criteria, these criteria can be eliminated from the matrix because they will not affect the decision. Some rules are needed (for example, if all are within 5 percent) to eliminate these criteria.

3. What is the significance of the measures used to indicate plan performance? General statements of goals will have to be interpreted by a set of quantitative and qualitative measures of plan performance. There is a need to ensure that the measures used adequately represent the interest of the goal and that they are sensitive to differences in plans.

4. Can the criteria be interpreted on a linear basis? For example, is a travel time of 10 min really twice as bad as one of 5 min?

5. What are the threshold values of certain criteria? There may be certain minimum levels of goal attainment that are necessary for an alternative to be considered. If this is the case, procedures must be developed to determine these values.

6. How will value systems be represented? Certain criteria are more important than others and there must be a procedure to determine a value system. This could also be a set of value systems if different subgroups of people are being examined.

7. Who will do the evaluation? Who will be involved in the evaluation process and how will this involvement take place?

8. Who will make the decision? What is the relation between the decision maker and the persons developing and analyzing alternative plans? How does communication take place?

9. What are the mechanics of the evaluation procedure? How will the various persons and committees involved operate? What are their information needs? What turnaround time is needed? How well-defined are the roles of the various persons involved in the process?

Interpretation of Evaluation Results

Once a tentative decision has been made there is a need to make it a strong decision. Interpretation of the decision is necessary to develop confidence in the choice made and to assess its relative merit over other alternatives.

1. Are differences in the preferred plan significant from a sensitivity point of view? The selection of a plan may be sensitive to a number of factors such as basic input data, definition of networks and zones, types of models used, parameters of the models, choice of criteria, parameters used in the evaluation itself, and procedures used to interpret the evaluation matrix. If slight changes in key parameters and assumptions shift the choice, further work to refine the choice may be necessary.

2. How well does each plan perform in situations that may not be probable but are still possible? An analysis should identify the possible contingencies, describe how they might occur, forecast the performance of the alternatives in the contingent situation, and compare these performances. Plans that perform well in a contingent situation should be preferred to those that do not. Some contingencies that might be considered are changing population and economic conditions, changing resource availability and environmental conditions, changing land use patterns, and changes in governmental policies.

3. What are the variations in plan performance that are necessary to make the second-best plan equal to the preferred plan? If these variations are major differences, there should be a greater degree of confidence in the preferred plan than if they are minor differences.

4. How well do the criteria reflect the goals? How can they be interpreted to reflect the goals? What are the subjective interpretations of how well each plan meets the goals?

MULTIDIMENSIONAL EVALUATION PROCESS

Evaluation can be conducted at a number of different levels. It can be conducted at the overall regional level,

for subareas of the region, for subgroups of the population, and for different periods in time. What may be a good plan at one level may not be a good one at a different level. If a plan performs well at the regional level, it should be further analyzed to determine how well it performs at some of the sublevels. Since the process of land use and transportation planning is a continuing one, some subregional evaluations should take place before and during the process of implementing a regional plan. It is important to clearly define the decisions that properly should take place at the regional or systems level and those that can be properly considered at a later stage. The initial evaluation should be undertaken with a set of alternatives that define a broad spectrum of options. From the testing of these initial alternatives, a second series of alternatives should be developed to represent the balance between the extremes of the earlier alternatives. This second set of alternatives should be tested against a wider set of criteria and under alternative future conditions, and it may be possible at this point to eliminate a number of alternatives because of obvious shortcomings or inferiority. Certain other plans may be eliminated because they seriously fail to meet overriding considerations for plan development and thus cannot be implemented. This would narrow the choice to a few alternatives that could be studied in greater detail at the regional level. In this analysis, the alternative plans would be compared to each other on an objective-by-objective basis.

After the regional level analysis, additional analyses can take place by subarea, subgroup, or time period. After these analyses, a tentative choice would be made and would then be subject to interpretation to determine whether it is a valid choice. If the tentative choice meets further tests and analyses, it can become a final choice and move toward regional adoption. All of the steps in the process should be fully documented and presented to the decision makers at key points in the process. The sequence of steps that would be used in the overall process is given in the following sections.

Feasibility Test of Each Alternative Plan

Each plan should be tested to see whether it meets the needs of the overriding considerations for plan development. These considerations might, for example, be that each proposed alternative must constitute an integrated system, that it must be within the economic capability of the agency to implement the plan, and that the plan must be in compliance with national and state regulations and standards. If a plan fails one or more of these tests, it should be dropped from further consideration, although if some dispute exists as to whether or not a plan meets the needs, the plan should remain for further analysis at subsequent phases of the evaluation.

Overall Evaluation

The remaining alternatives should then be compared on a regional level, but a plan should be acceptable on an overall basis before it is examined on a sublevel basis. The following steps should be used for such an evaluation.

1. Test the adequacy of the measures used as criteria. The means used to measure how well an objective is met should be reexamined to determine whether they portray the objective in a proper manner. Criteria can be measured as totals, averages, or as a net change over a base. The change caused by a plan may be insignificant when compared on a total or average basis but significant when the increment over a base value is examined.

2. Develop a set of rules for eliminating criteria. If all plans are equally or almost equally successful at meeting certain criteria, those criteria will not affect the decision and can be eliminated.

3. Eliminate criteria by using the rules developed in step 2.

4. Eliminate plans by principle of dominance. If any plan falls below any other plan in all criteria, it is dominated by the superior plan and can be eliminated.

5. Examine the remaining criteria to determine those that are (a) threshold values that must be met, but are not significant beyond that, (b) characteristics of the input used to develop the alternatives, or (c) representative of differences in the ability of each plan to meet the overall objectives. Possibly some of those in the first two categories can be eliminated since they may not be relevant to the decision.

6. Combine criteria where possible. If a set of criteria are similar in what they are measuring, they can be combined into a single measure.

7. Repeat steps 3, 4, and 6 as often as necessary until no more changes occur. At that point, a reduced evaluation matrix in which no one plan dominates and all criteria measure significant differences in the remaining alternatives will remain. The subsequent steps in the evaluation will be aimed at defining the trade-offs between the alternatives and the issues involved in each choice.

8. Study the marginal costs and gains. Arrange the remaining plans in order of increasing costs and examine the marginal gains as the costs increase in a manner similar to marginal benefit-cost analysis. Some plans will have a lower marginal gain per unit cost than others at this point and can be dropped from further consideration.

9. Define the trade-offs. By this point the matrix will be reduced to a more manageable size and the differences between plans should be evident. These trade-offs should be defined, and an attempt should be made to present the issues involved in as concise terms as possible for the decision makers. The trade-offs can be developed by comparing the alternatives in pairs in a sequence of increasing costs and should indicate the gains that would occur if the more expensive plan were chosen over the less expensive one and the costs necessary to obtain these gains.

10. Develop additional alternatives. At this point new alternatives that combine some of the best features of the earlier alternatives may be developed. These alternatives would then be analyzed in a manner consistent with the original alternatives and carried through the above processes.

11. Select plans for sublevel analysis. From the information obtained from steps 2, 9, and 10 certain plans can be eliminated from further consideration because they are unacceptable at the overall level. Among the plans that are acceptable, there are three possible outcomes: (a) One alternative may be clearly preferable to the others in nearly all respects; (b) a number of alternatives may be essentially equal in nearly all categories; or (c) some alternatives may excel in some categories and others may excel in other categories, but there will be no clear choice without serious trade-offs. Except for the first outcome, further analysis at the sublevel is necessary.

Sublevel Analysis

The plans can be evaluated by subarea, subpopulation

group, or for different time periods.

Tentative Selection Among Alternatives

This selection should be labeled as a tentative choice and will require careful interpretation before it becomes the final choice. It is important that this distinction be emphasized so that an objective interpretation can take place. The option of changing the tentative choice should remain open, and adequate time should be allocated to the interpretation phase so that all analysis (and iteration, if necessary) can be done.

Interpretation of Tentative Selection

Once the tentative selection has been made, it should be interpreted in order to strengthen the choice. The process of alternative development and testing involves a series of simplifications and assumptions that must be examined to determine their effects on the choice, and certain factors that have not been explicitly included in the analysis and their effects on the choice should also be examined. The interpretive phase should involve the following activities (not necessarily in the sequence shown).

Break-Even Analysis

This is an analysis of how much better the best alternative is than the second-best. Such an analysis is relatively easy to perform with single-number evaluation techniques. An important question is, are the differences between the best and second-best alternatives significantly large enough that they are not within the range of differences that might be expected from the data and procedures used? Such an analysis would be conducted in a manner similar to the marginal cost versus gain process described in step 8. The marginal gain of the best plan over the second-best plan should be examined in relation to the process used to delineate the differences in the plans. If the differences are beyond the range of variance due to the forecasting techniques, there should be a greater degree of confidence in the best plan than if the reverse were true.

Sensitivity Analysis

The purpose of this analysis is to identify the effects of the various parameters and assumptions used in the forecasts and evaluation. The results of the forecasting procedures may be very sensitive to some parameters and insensitive to others. The sensitivity analysis can be directed at the criteria themselves or at the data processing effort. In the first case, the sensitivity of the choice of the best alternative to the means used to define a criterion is examined. In the second case, the sensitivity of the data used and forecasting techniques are examined. Obviously the second case would involve considerably more effort than the first. For example, it might involve the following steps: (a) Identify the parameters used in the forecasts; (b) examine the range of values used; (c) review the process used to set values on the forecasts; (d) estimate the possible range of values the parameter could have as the result of statistical, conceptual, or assumption errors; and (e) determine how these errors would be carried through the process and how they might have a differential effect on the different alternatives.

Contingency Analysis

A contingency is an event whose occurrence is possible but not probable. For example, the effects of severe long-term shortages in petroleum-based fuels, the effects of major changes in population growth, or the effects of major shifts in land use patterns might be viewed as contingencies. Because of the uncertainty of the future, it is desirable to examine how well the best alternative performs under contingent situations. Such an analysis might involve the following steps: (a) Identify the contingent situations, (b) develop scenarios as to how they would occur, (c) forecast the performance of the best alternative under the contingent situations, and (d) compare the performance of the best alternative under normal and contingent situations.

Impact and Incidence Analysis

The impact (upon whom) and the incidence (at what period in time) of the costs and gains associated with the best alternatives should be examined. The costs and gains for two plans may be very similar in the aggregate but very dissimilar in their effects on those who receive them or the times in which they occur.

Implementation Feasibility

The relative ease with which a plan can be implemented should be examined. A superior plan with a low probability of implementation might be rejected in favor of a lesser plan with a higher probability of implementation. In addition, plans might be combined to increase implementation probabilities or efforts might be made to reduce barriers to implementation if they can effectively be identified.

Qualitative Analysis

This is a catchall that would include a careful examination of the best choice in the light of factors omitted in the analysis, assumptions made, factors that could not be quantified, uncertainties, and the results of the other phases of interpretation.

Table 1. Hypothetical evaluation matrix.

Criterion	Plan A	Plan B	Plan C	Plan D
1. Maximum transit headways	Met	Met	Met	Not met
2. Transit use to major trip generators, %	40	42	41	42
3. Congested highways, km	175	85	70	72
4. Average speeds, km/h				
a. Transit	20	25	25	25
b. Highways	51.3	51.6	51.8	52.0
5. Total daily vehicle hours	125 000	123 000	122 000	121 000
6. Households displaced	0	450	1250	1320
7. Businesses displaced	0	45	125	195
8. Annual public cost, $	20 000 000	60 000 000	90 000 000	100 000 000

Note: 1 km = 0.62 mile.

Feedback

The plans developed should be presented to the appropriate agencies and persons for their reactions and subjective evaluation. This should be a continuing process throughout the evaluation phase. The information developed in the previous steps should be sufficient to focus on the differences among plans so that a well-thought-out decision can be made.

Modification of Plan

It is probable that in the evaluation and interpretation of alternative plans for the region certain features of one plan might be combined with other features of another plan. Such opportunities should be explored and tested whenever they occur although it may be necessary in some cases to return to earlier steps to compare the modified alternative with the other alternatives.

Selection of Plan

From the information and analyses developed above, it should be possible for the appropriate persons to select a plan of action. Once this plan has been selected, it should be adopted by the appropriate agencies and efforts should be initiated to determine the steps necessary to implement the plan.

EXAMPLE

The multidimensional process described in the preceding section can be illustrated by a simple example. Four hypothetical plans are to be evaluated against nine standards as shown in Table 1. These four plans are all feasible. Plan A is the do-nothing alternative, plan B is an alternative with limited investment in new facilities, and plans C and D both involve major investments in new facilities. The number of criteria has been limited to conserve space, but it should be recognized that additional criteria beyond those shown should be used in an actual evaluation. Criteria 2, 4b, and 5 can be eliminated since they show few significant differences among the plans. Criteria 6 and 7 can be combined since they both are measures of disruption and are roughly proportional to each other. Plan D can then be eliminated since it is dominated by plan C, and once plan D is eliminated, criterion 1 can be eliminated. The resulting evaluation matrix, shown below, has three alternatives and four criteria.

Criteria	Plan A	Plan B	Plan C
3	175	85	70
4a	20	25	25
7 and 8	0	495	1375
9	20	60	90

The choice of a plan then reduces to an examination of the trade-offs between the plans.

Plans	Trade-offs
B versus A	Gains: Reduction of congested highways by 90 km; increase in transit speeds from 20 to 25 km/h Costs: Displacement of 495 businesses and households; extra annual public cost of $40 000 000
C versus B	Gains: Reduction of congested highway by 15 km more Costs: Disruption of 880 additional properties; additional annual public cost of $30 000 000

Plan B provides a reduction in congestion and an increase in transit speeds at the cost of some disruption and an increase in cost. Plan C further reduced congestion, but by a small increment and at the cost of further disruption and increases in cost. This information and earlier steps should be given to the relevant decision makers and advisory groups for their consideration. The final choice of a plan then becomes a question of the relative degrees of importance placed on each of the associated gains and costs.

This example illustrates that the issues involved in a complex decision can be successfully identified through a process of carefully narrowing the choices and the criteria used for evaluation. Such a process can be used as an effective aid to decision making and to overcome some of the shortcomings inherent in overly mechanical techniques of planning evaluation.

SUMMARY

This paper has examined the process of evaluating alternative transportation plans in an attempt to provide an overall structure to the process. This has been done by presenting a series of questions that must be answered prior to any evaluation effort and by presenting a technique that can be used to narrow the choice to a limited number of alternatives having significant trade-offs among them. It is important that the process of evaluation be given careful consideration and substantial effort, but it is even more important that the techniques for evaluation be viewed as aids to decision making and not as the means for making decisions. That process is one that should be made through the best judgment of the decision maker with proper consideration of the trade-offs among the alternatives and the implications of the choice. To assist the decision maker in making this choice, there should be careful efforts to ensure that the criteria and measures of effectiveness used in evaluation are closely related to the goals of the plan, and the careful interpretation of the choice in the light of contingencies, sensitivity-omitted factors, and nonquantifiable factors should be viewed as an important part of the evaluation process.

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Transfer Optimization in an Interactive Graphic System for Transit Planning

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This paper describes a coordinated four-stage interactive graphic process for operational transit planning. Stage 1 deals with route, headway, and vehicle-type optimization; stage 2 attempts to optimize transfer delays; stage 3 designs runs so that the service resulting from the previous stages can be operationalized; and stage 4 provides computer assistance in making manpower assignments. The network optimization procedure of stage 1 has been previously reported on, and the latter two stages are currently under development. This paper deals principally with the transfer optimization tool of stage 2. The operational tool to optimize transfer delays involves the automated-iterative modification of terminal departure times. An interactive graphic computer approach is used to increase the transparency of the tool to the planner. The analysis takes into account the calculation of expected waiting times for transfers between transit lines with different headways and the interdependence of terminal departure times. Within the interactive graphic optimization process, the user can request computer-generated and computer-drawn charts of transfer movements and delays, time-distance diagrams of individual routes, and computer-produced transfer statistics at individual stops as well as the entire system. The process has been applied to the Basel Transit System in Switzerland, which serves a population of 500 000. In comparison with the existing hand-generated timetable, the optimized timetable reduces the total transfer delays by approximately 20 percent with no increase in operating costs.

Operational transit planning has a short time horizon and for our purposes can be described as shown in Figure 1. The input to this planning process is a number of items that must, in the short run, be fixed. These items are the demand for transit service in terms of trip origin and destination (O-D), which are stratified perhaps by time of day; a base network (existing rail right-of-way and arterial streets), terminals, depots, and other infrastructures; and the characteristics of available rolling stock.

The planning process should generally be guided by user objectives (e.g., minimum total travel time); it is constrained both by the financial considerations of the operator (e.g., maximum allowable deficit) and by existing labor contracts (e.g., required terminal layovers). The desired output from the operational planning process is the transit routes, the vehicle types serving each route and the headway with which they are served, the timetables, the runs used to operationally service the routes, and the vehicle and driver assignments.

INTERACTIVE GRAPHIC APPROACH

Past experience has shown that, given the current state of our analytic tools and of computer hardware, it is impossible to treat the entire operational transit planning process in one step as shown in Figure 1. In the past, the approach has been to treat subareas of the total problem separately, and in most cases disjointedly, and to apply to each subproblem an analytic technique that seemed best suited to it. The methods that have been used in the past include simulation-modeling techniques to design bus routes; mathematical programming techniques (integer programming); and heuristic techniques to construct timetables, define runs, and assign vehicle and driver resources. A useful description of some of these past efforts is given by Wren (1). The following principles were used as guidelines to approach the problem of operational transit planning.

One of the principal desires was to make the entire process as transparent as possible to the transit planner and to adapt as many as possible of the planner's existing methods and tools. This desire was motivated by the fact that highly sophisticated, but nontransparent, computer models that employ drastically different methods are only reluctantly accepted within the existing planning and operations framework of transit properties.

It was also decided to build the entire operational planning tool around an environment of minicomputer hardware by using low-cost storage tubes (cathode ray tubes) as shown in Figure 2. Currently, only this type of environment gives the user the quick response time needed, and at a price that is compatible with small and medium-sized transit operators. In the network optimization stage, a computer with 32-K words memory can analyze a transit network with 250 nodes, 950 links, and 60 lines. (This memory is automatically expanded to account for transfer movements to 700 nodes and 2300 links.)

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Third, and most important, all the functions of operational transit planning had to be coordinated into a unified process. The operational planning process that resulted from these considerations is shown in Figure 3. The problem was segmented into four stages so it could be tractable with minicomputers and existing analytic techniques. However, the data flow between stages is explicitly linked to highlight the dependence of one analysis stage on the output of the preceding one and to maintain the desired coordination of the process as a whole. To increase the transparency of the process to the planner and to facilitate the adaption of existing operational planning tools, we adopted the interactive graphic person-computer approach. This technique, as demonstrated in past applications, has the added benefit of allowing the discovery of near-optimal solutions by use of simple analytic techniques and low-cost computer hardware (2, 3, 4).

Stage 1 (network optimization) has been previously reported on (5) and documented (6). This stage was applied to the problem of coordinating the suburban and urban transit routes in the Basel, Switzerland, area. Optimum solutions to this problem, defined by planner objectives and limited by the iterative search process, were efficiently generated (7). This paper describes stage 2 (transfer optimization), which has recently been operationalized. Stages 3 and 4 (run allocation and manpower assignment procedures) are currently under development and will be reported on later.

TRANSFER-OPTIMIZATION PROBLEM

Except in the case of a highly sophisticated, fully automated transit technology, e.g., personal rapid transit (PRT), most transit operations will require some transfer movements from one route to another to serve the diverse origin-destination patterns of the current urban agglomerations. To minimize the adverse effects (in terms of the competition between public transit and private automobile), the transit operator must try to (a) reduce the required number of transfers by adjusting the routing to the given O-D pattern of transit trips and (b) minimize the transfer delays (i.e., the waiting time at the transfer point). As shown in Figure 2 and described elsewhere (5, 6), the first part of this problem is solved during stage 1. Thus, transfer optimization can be attained by minimizing transfer delays.

The typical operating day of a transit system can be divided into a number of periods that are characterized by the level of demand and thus the headway that can be justified. Typically, there will be the morning and evening peak periods during which demand is high and consequently the headways rather short (from less than 1 min to about 6 min) and the off-peak periods during which headways can range from 15 to 60 min. The minimization of transfer delays will be treated separately for each of these periods of constant headway. Since, in general, the waiting time is proportional to the headway, it is primarily in the off-peak periods that transfer optimization is important.

The transfer situation at a given stop is shown in Figure 4, and the waiting times between stops on the

Figure 1. Operational transit planning defined by input and output.

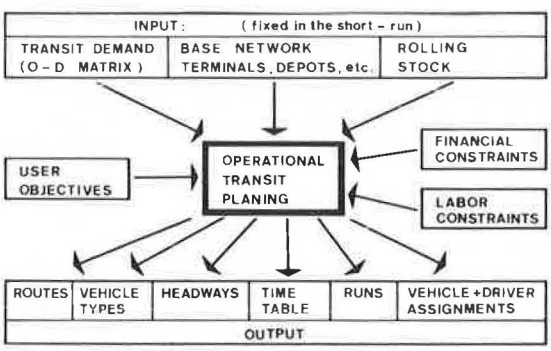


Figure 2. Typical storage terminal for interactive graphic data.

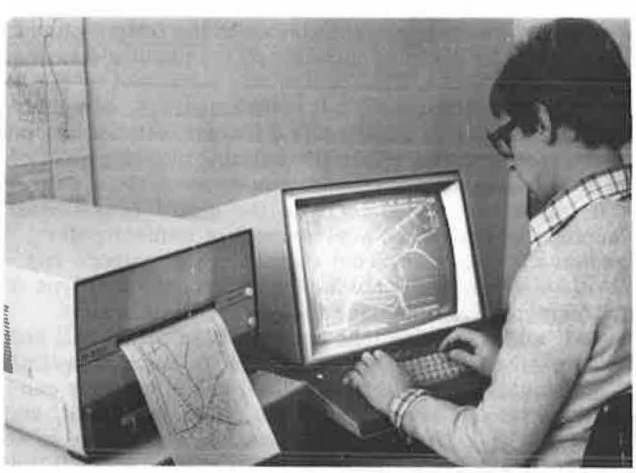
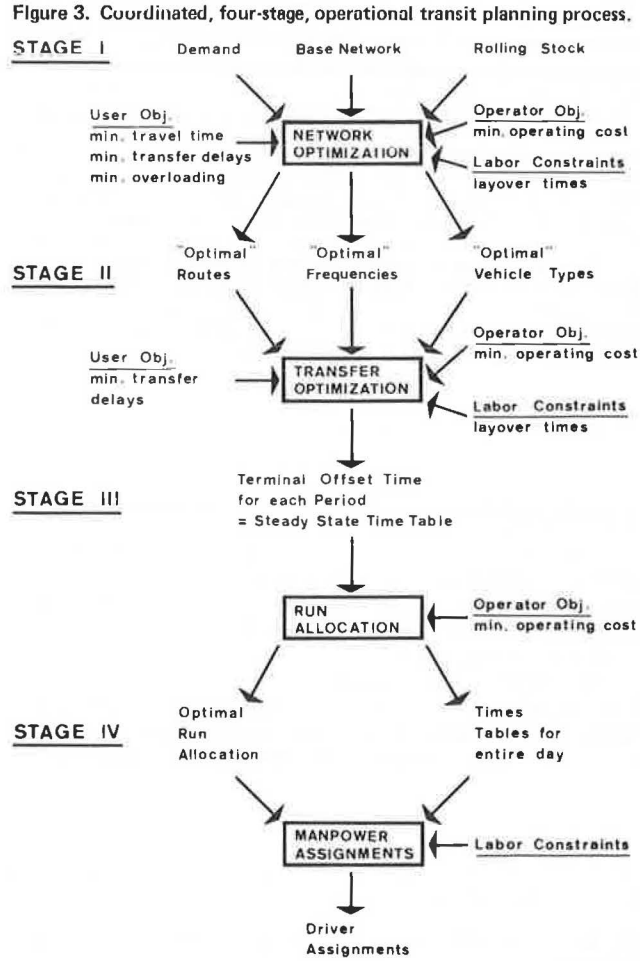


Figure 3. Coordinated, four-stage, operational transit planning process.



Basel Transit System are given in Table 1. As given in Table 1, the longest wait (5.5 min) occurs for transfers from line 36 at stop KU to line 15 at stop TE. This waiting time could be reduced to 0 min by moving line 36 ahead by 5.5 min, thus reducing the total waiting time (average waiting time × number of transfers) by 38 min. However, the 23 passengers wanting to transfer from KU to STB would miss their connection, and their average waiting time would increase by 5.5 min. Added complications arise from the following:

1. Since a given line will intersect more than one other line, then a change in arrival-departure times at one stop will have repercussions at a number of other transfer points;
2. Since the headways on two intersecting lines need not be the same, then the optimization of the transfer at one point in time will not necessarily yield an overall optimum transfer situation, even at one stop; and
3. Since the arrival and departure times are directly linked to terminal layover times, and layover times are constrained by labor regulations, then more vehicles will be needed to serve a given route, if the layover times are longer.

Thus, transfer optimization can be attained by an interactive modification of arrival and departure times at stops. This modification is used to reduce the total waiting times throughout the system by taking into account the added complications of multiple-transfer points on a given line, nonuniform headways between lines, and the interdependence of layover times and vehicle requirements.

INTERACTIVE GRAPHIC TRANSFER OPTIMIZATION

Network Optimization

The interactive graphic computer approach to transfer optimization is part of a coordinated operational transit planning process. As such, the input to the transfer optimization is derived directly from the network optimization (stage 1). Thus, the following is a brief overview of the network-optimization system (NOPTS). Basic input to NOPTS consists of a base network (existing streetcar and subway trackage, subset of the street network suitable for bus transit, and some pedestrian connectors), a transit-trip O-D matrix, and the characteristics of available rolling stock (capacities and operating costs). A transit system is then designed interactively by specifying the routings, vehicle types, and frequencies of individual lines. A multipath stochastic model (8, 9) is used to assign the demand to the system of routes. This assignment allows the calculation of some performance parameters of the particular transit system design. By iterating this design-evaluation cycle, the planner can quickly approach an optimum transit network design that is indicated by the choice of design objectives (e.g., minimize operating costs and number of required transfers).

The output from this iterative procedure for network optimization that is important for the subsequent transfer optimization is (a) the selected (optimum) route structure and headways for each line; and (b) at each transfer point, the number of transfer motions between all applicable pairs of transit lines. The fact that the detailed transfer movements can be retrieved from the trip assignment is an important feature that is obtained by using Dial's algorithm (8). As previously mentioned, transfer optimization is conducted separately for each operating period during which headways are constant, and, thus, the route-headway optimization must also be done for each of these operating periods.

Minimization of Transfer Delays

Since the operating period is a portion of the daily operation during which headways remain constant, then a particular transit line is completely described in time and space, during such an operating period, by the following three parameters:

1. The geographic routing (i.e., sequence of stops),
2. The headway (i.e., the time interval between vehicles passing a given stop), and
3. The terminal offset times (i.e., the time delay, at both terminals of the line, that begins at the start of the operating period and continues until the departure of the first vehicle).

Parameters 1 and 2 result from the network optimization described above, and parameter 3 represents the primary design variables for the transfer-optimization procedure. The iterative design process is aimed at finding a set of terminal offset times that will minimize the aggregate transfer delays systemwide; however, the process is constrained by the operator's desire to keep the operating costs (i.e., the number of vehicles required) at a minimum.

This cost constraint is important because it limits the degree of freedom with which terminal offset times can be varied. This phenomenon is observed in Figure 5, which shows the time-distance diagrams. The terminal offsets (the design variables in the interactive graphic process) shown on the upper diagram have the effect that three vehicles are needed, whereas, in the offsets shown on the lower diagram, one vehicle can be saved without violating the minimum layover time requirements.

In the optimization process, the terminal offsets (departure times at any intermediate stop) are repeatedly varied with the objective of reducing the transfer delays systemwide. The complications of multiple line-crossings, nonuniform headways, and the relation between layover times and vehicle requirements are automatically taken into account. To this effect, the planner can demand the following tasks:

1. Display graphically the internal desire lines of any transfer point;
2. Perform input and interactive editing of terminal phase offsets;
3. Display the current set of terminal offsets, layover times, and the corresponding number of vehicles needed;
4. Display the transfer statistics (arrival time, departure time, number of transferring passengers, wait times) between any pair of lines at any transfer point;
5. Display global statistics (sum of transfer delays, etc.);
6. Display time-distance diagrams of any transit line;
7. Print timetables (departure times at all stops on any line); and
8. Move departure times of lines or groups of lines forward or backward.

The number of possible transfer movements (i.e., direction-specific pairs of lines at each transfer point) is very high, even in a medium-sized city (1200 to 4000). Therefore, it would be impossible to find optimal solutions without some degree of automation. A heuristic technique was developed that searches all the possible terminal point phase offsets of one line (directional) and selects the one offset that produces, with all crossing or parallel lines, the shortest total of transfer delays. The

search process is repeated until the total systemwide delays can no longer be reduced. Of course, the heuristic technique is only able to locate local minima, and it is dependent on the starting point (in terms of the set of initial phase offsets) and on the order in which the transit lines are treated in the iterative process.

SYSTEM APPLICATION

To demonstrate the potential reduction in transfer delays that can be achieved, we applied this system to the existing Basel Transit System shown in Figure 6, which had been coded for another project (6). The public time schedules were used to obtain the phase offsets at the evening off-peak period from 8:00 p.m. to 12:00 m.n. During this period, most lines have a headway of 12 min, and some lines operate every 15, 24, 30 or 36 min. A total of 82 vehicles were used. NOPTS was used to assign the evening off-peak transit demand to the network, and the number of transfers, the transfer point desire lines, transfer wait, and the total transfer delay (passenger-minutes per hour) were calculated for each stop. The total systemwide transfer delay for 82 vehicles operating on this existing service schedule was 20 544 passenger-min/h. This transfer delay represented the state in which an application of the transfer optimization can be used for improvement.

The heuristic technique was applied, and a minimum in the total transfer delay was achieved. This minimum was 15 600 passenger-min/h or a reduction of about 25

Figure 4. Transfer movements at a typical transfer point.

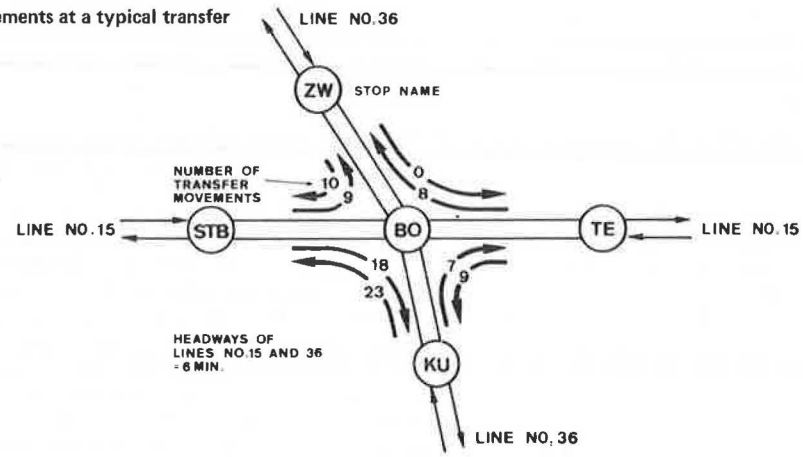


Table 1. Waiting times between example stops.

From Stop	Line	Arrival at BO (min)	To Stop	Line	Departure From BO (min)	Avg Wait at BO (min)	No. of Transfers	Total Wait (min)
STB	15	5.5	ZW	36	6.0	0.5	9	4.5
STB	15	5.5	KU	36	7.5	2.0	18	36.0
TE	15	5.0	ZW	36	6.0	1.0	8	8.0
TE	15	5.0	KU	36	7.5	2.5	9	22.5
KU	36	0.0	TE	15	5.5	5.5	7	38.5
KU	36	0.0	STB	15	5.0	5.0	23	115.0
ZW	36	1.5	STB	15	5.0	3.5	10	35.0
Total								259.5

Figure 5. Relation between terminal offsets and vehicle requirements.

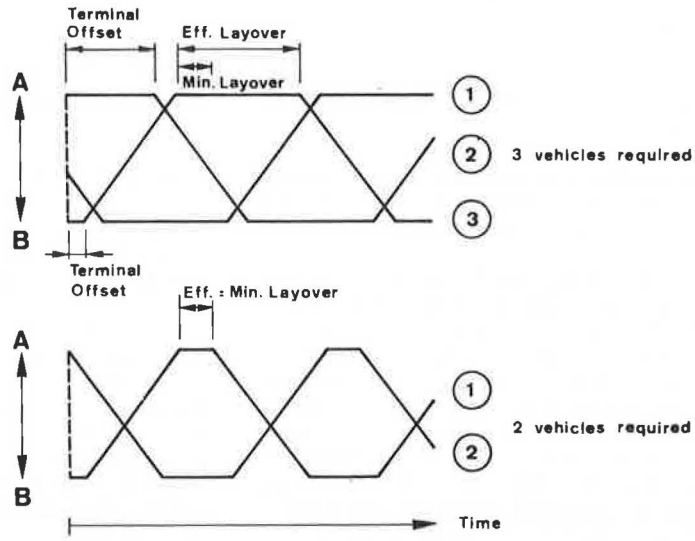


Figure 6. Line map of Basel Transit System.

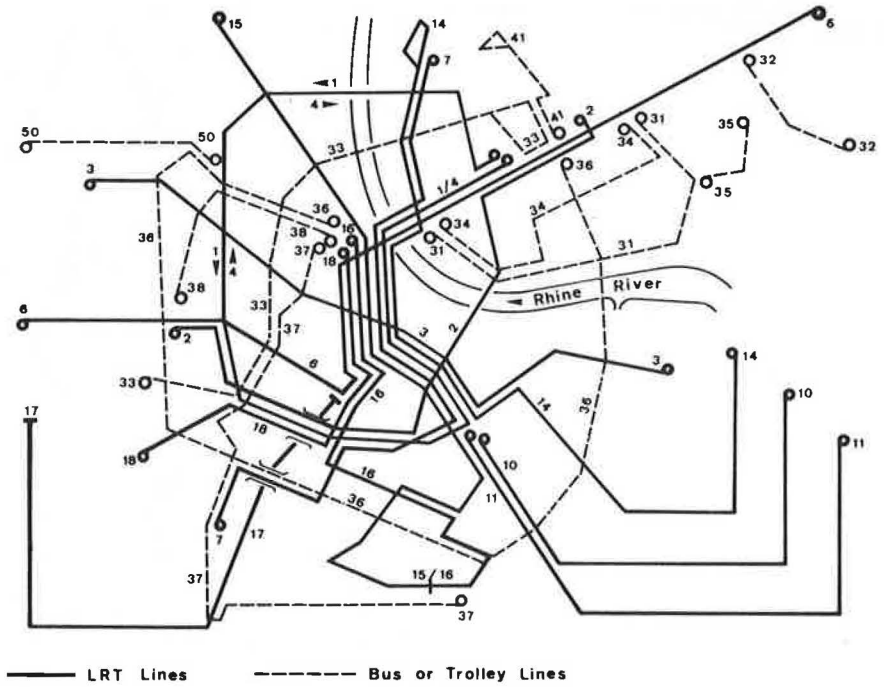


Figure 7. Transfer delay times before and after optimization.

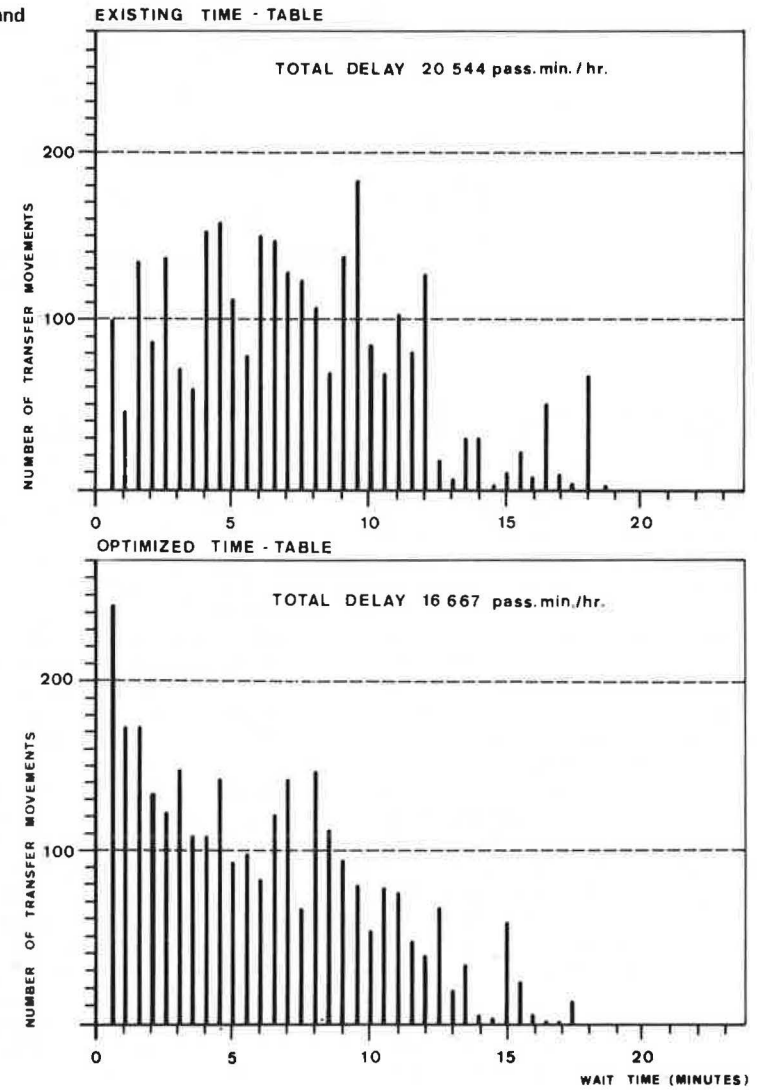
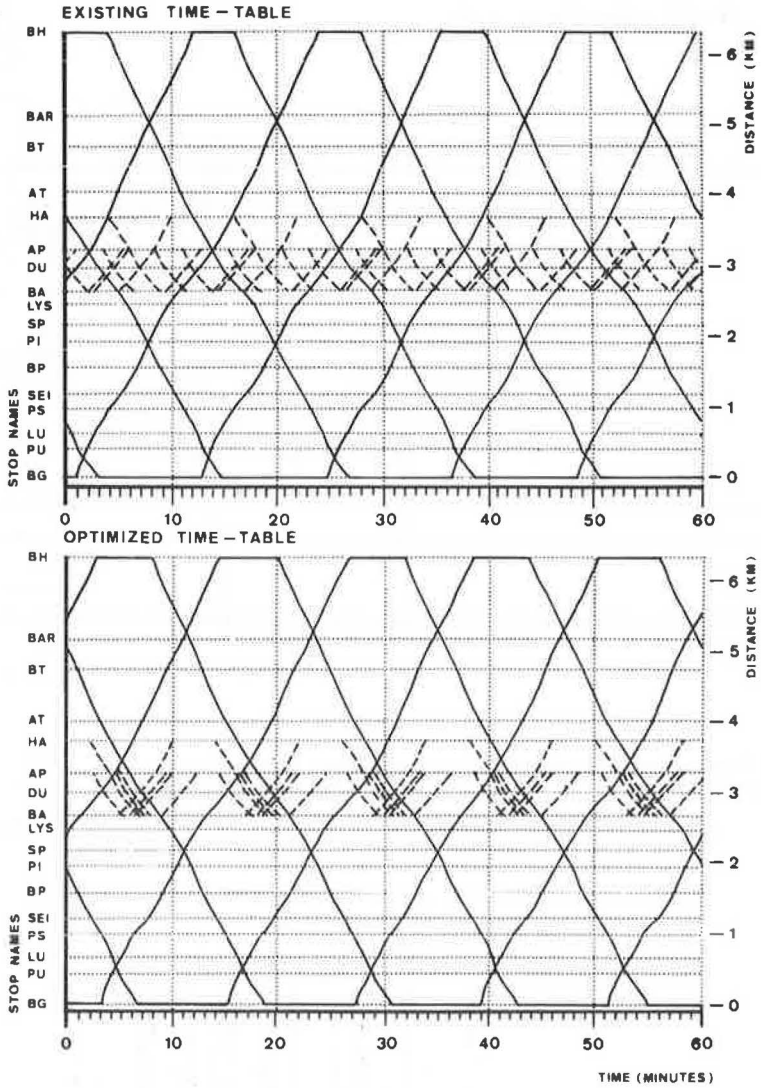


Figure 8. Sample time-distance diagram before and after optimization for line 3.



percent. The optimized set of terminal phase offsets proved to require 86 vehicles. Thus, a 25 percent reduction in total transfer delay was bought by an addition of 4 vehicles during this period.

With the aid of the time-distance diagrams shown in Figure 5, these extra vehicles can be eliminated; however, they can generally be eliminated only at the expense of increased transfer delays. After eliminating all extra vehicles by judiciously shifting the phase offsets at one terminal point of the affected lines, the total transfer delay increased to 16 667 passenger-min/h. This increase still represents a 19 percent improvement over the original state, and there is no increase in the number of vehicles (and drivers) or vehicle-kilometers.

Figure 7 shows the waiting time distribution. This distribution shows that the transferring passengers can obtain improved conditions with the optimized timetable. Whereas the existing handmade timetable shows an almost random distribution of waiting times in the interval between 0 and 12 min, there is a clear skew to shorter delays in the latter. This tendency could be accentuated if, in the optimization heuristic technique, longer waiting times were weighted more heavily than shorter waiting times.

Figure 8 shows the time-distance diagrams of one transit line. The horizontal axis represents time from the start of the operating period, and the vertical axis represents distance along the route. Each line corresponds to the time-distance description of one vehicle. The connections of lines at terminal points incorporate the minimum layover times required by labor constraints. The dotted lines in the diagram represent the runs of other transit lines along common links. It can be seen that the runs on the common links through the city center are evenly spaced in the case of the existing timetable, whereas the transfer optimization produces batches of runs. Clearly, the more evenly spaced intervals in the first case have the advantage of lower access waiting times for trips that begin and end in the city center, but the number of these trips is relatively small as compared to the number of transferring through trips. These time-distance diagrams are important tools for operational transit planners, and this is one of the reasons why they were included in the display options of the interactive graphic, transfer-optimization system.

Although much work remains in the development of a heuristic technique to assist in this transfer-optimization process, this application example has shown that there is a potential for improvement over the current operating conditions. The example was for evening-period operations only, but it can be safely projected that application of this method to all off-peak operating periods would reduce the transfer waiting times of the Basel passengers by 500 000 h/year. During peak periods, the payoffs are

smaller because of reduced headways (6 min on most lines), and it is difficult to maintain the timetables in mixed traffic conditions.

The example also highlighted the trade-offs that must be made between improving the level of service by reducing transfer delays and economic considerations, in terms of the number of vehicles needed to mount the service. It is in evaluating these kinds of trade-off possibilities that the interactive graphic implementation of the transfer-optimization system demonstrates its greatest use.

LIMITATIONS OF APPROACH

Implicit in the way the problem of operational transit planning has been approached, there are a number of simplifying assumptions. The most important of these assumptions is that both transit travel demand and number of transfers are fixed. One basic input to this operational transit planning process in general, and the network-optimization stage in particular, is the demand for transit trips. It is thus assumed that changes in transit routing and level of service will not affect the demand for the short planning horizon of interest. The primary reason for making this assumption is that data on transit trips are generally more available than those for travel demand in general. It also avoids the necessity of modal-split modeling, which includes additional data requirements and uncertainty.

Each alternative design during the network-optimization stage will, in general, result in a different network loading (as predicted by the multipath assignment algorithm). These loadings are based on expected transfer waiting times. The transfer optimization, as a separable problem, assumes that transfer time optimization will not significantly affect loading patterns. This decision of problem separation was made primarily on the basis of computational efficiency: Recomputing assignments after every transfer time alteration would increase the computing time to the point of making the interactive approach of questionable use.

CONCLUSIONS

In the past, planners have frequently criticized transit operators for a lack of flexibility in adjusting the transit service to the changing demand patterns. Even within transit companies, route and service planners have often found opposition from the operations departments to adjusting the routings and levels of service to the user's observed patterns of change. On the other hand, the operations departments have criticized planners for a lack of understanding of the complexities of frequent route and service changes in terms of the requirements for schedule coordination, run design, and manpower allocation. Thus, a formalized coordinated procedure is needed that will account for both the planners' objectives and the constraints of operations. It is felt that the coordinated, four-stage, operational planning tool discussed in this paper is a first step in this direction.

The transfer-optimization procedure, as stage 2 in this operational planning tool, considers in detail the line-to-line transfer movements, the complexities of nonuniform headways among transit lines, and the constraints imposed by the linkage of labor requirements, which relate to minimal layover times and the numbers of vehicles needed and thus the operating cost. If this search technique is applied to this complex problem, then the special skills of schedulers and operations experts can be combined with the data-handling powers of the computer. Its application should help transit companies to serve their customers better without increasing their deficits.

ACKNOWLEDGMENTS

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Computer-Generated Films to Document and Demonstrate Transportation Simulation Models

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Although simulation has been shown to be a valuable tool for the design and analysis of complex transportation systems, the use of available simulations by transportation planners has been constrained by the difficulties in assessing the applicability of a particular model and, then, understanding the operation of the model well enough to apply it effectively. The use of computer-generated films to supplement conventional documentation is proposed as a means to efficiently disseminate information about models to potential users. These films can show which real-world features are and are not explicitly represented in the model and show in an easily assimilated graphic form the complexities of model dynamics. Two computer-generated color films have been produced that illustrate the application of this type of documentation. One film shows the operation of the urban traffic network simulation model. The second film illustrates the application of the film techniques that document the transit station simulation model.

For many years, use of computer simulation has been recognized as an effective means of analysis for large-scale transportation systems such as airports, rapid transit systems, and urban highway traffic networks. Since there has been an increase in the complexity and cost of such systems, the U.S. Department of Transportation has recognized the need for using more scientific quantitative techniques to design these systems and has sponsored the development of a number of simulations that are being made available for general use by the planning community (1, 2, 3).

Although these simulations are generally supported by comprehensive multivolume documentation, the complexity of the models is such that it requires a major investment of the potential user's time to learn about the model and to determine if it is applicable to the user's particular problem. To use the model effectively, the user must understand it well enough to be able to translate the real-world problem into the often abstract structure of the model and to set the model parameters correctly. If widespread use of the available models is to be encouraged, and the potential user's understanding of the model operation is to be assisted, then improved forms of documentation are required.

One attractive possibility is the use of computer-generated films that can show, in an easily assimilated visual form, how the model works. Such films have been used successfully to demonstrate operations of a complex system (4) and to aid in the validation of simulations (5). The models used for these films, however, were microscopic simulation models that were specifically designed to provide graphics output. However, most existing simulation models were not designed with graphics in mind. Therefore, modifications might be required in the program, and an interface program will have to be developed to produce the graphics. If the graphics are to show movement of individual entities, it is necessary that the simulation be microscopic. If entities are aggregated, as in macroscopic simulations, flow and other quantities can be indicated by analog symbols such as arrows with the size of the symbols proportional to the flow rate or the quantity being indicated.

The effectiveness of the computer-generated films for showing simulation operation can be substantially enhanced if the computer-drawn images are superimposed optically, during film processing, on a pictorial art work background that depicts the environment in which the system operates. I have used this technique extensively for the production of airport simulation films (4) and a rapid transit film (5). A second technique for showing environmental features is the use of colors for the computer-generated images. This technique was used to produce the two test films. These films demonstrate use of the technique to document and demonstrate the operation of the two simulations developed by the U.S. Department of Transportation. Although neither of these simulations was originally developed with graphics in mind, they are both microscopic simulations, and interface programs were developed to demonstrate the operation of the simulation.

URBAN TRAFFIC NETWORK SIMULATION MODEL

The use of color for the computer-drawn images was of particular interest in the films made by the Federal

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Figure 1. UTCS1 network schematic for case study.

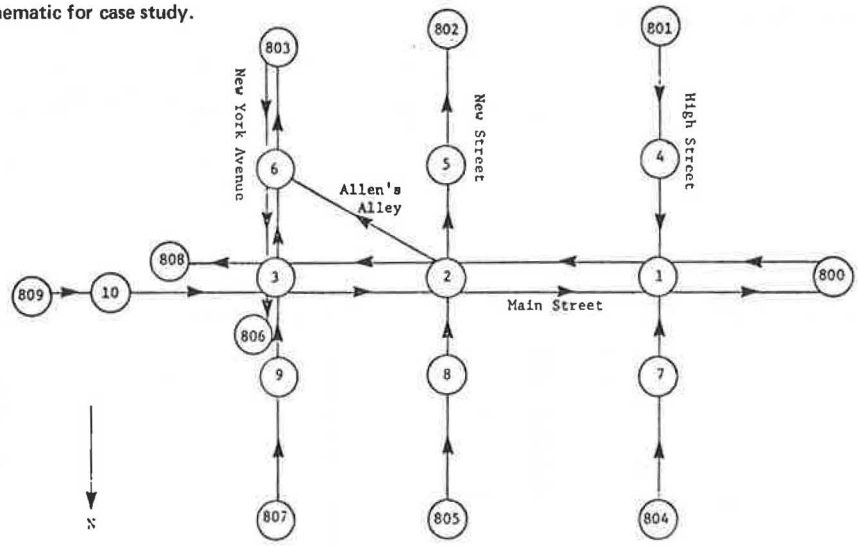
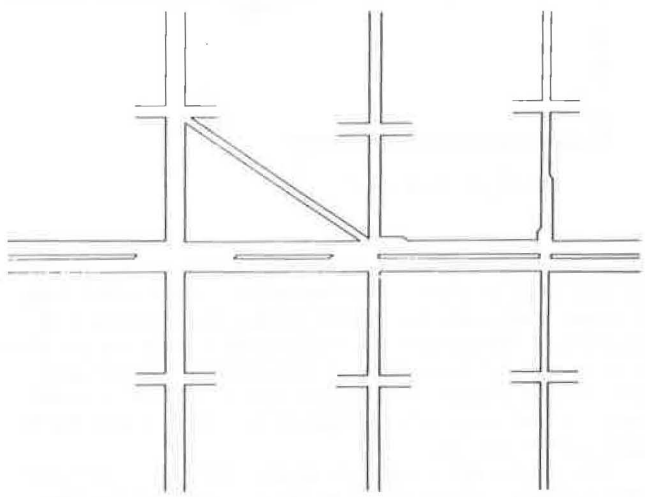


Figure 2. UTCS1 network geometry for case study.



Highway Administration for the Urban Traffic Network Simulation Model (UTCS1). This model is a microscopic network flow simulation that was designed for investigating urban traffic control strategies by emphasizing the relatively sophisticated signal control schemes.

The use of color made it easy to show the red, green, and amber traffic light operation in a sufficiently realistic manner so that the operation of traffic control over a portion of network can be easily assimilated by the viewer. The vehicles (buses, trucks, and cars) are shown as white figures of appropriate length and width, and street outlines, bus stops, and other aspects of the environment are shown in a subdued blue. The ratio of projection speed to real time can be varied to achieve different effects. For large networks shown at high speeds, the gross flow patterns and platooning of vehicles are clearly evident. For the relatively small networks shown at slow speeds, the microscopic logic of the simulation can be easily studied. The UTCS1 capabilities that are demonstrated in this film include car following, lane switching, queue discharge, left-turn gap acceptance, stop-street gap acceptance, lane blockage, fixed-cycle and actuated signals, turn pockets, lane channelization, pedestrian-vehicle conflict, bus operations and station dwell, left-turn jumpers, and amber phase response.

Shown in Figure 1 is the network adopted for the test film. This network was also the case study network used in the UTCS1 manual (3). Since the model was not designed for graphic output, the links are characterized only by length (stop line to stop line), and the intersections do not have explicit X and Y coordinate assignments. Before the model is run for graphics purposes, it is necessary to establish a street geometry on an XY grid such as that shown in Figure 2. This grid is compatible with the model input data. The UTCS1 model was modified to produce the necessary data for input to the graphics program. Since turning behavior at intersections is not explicitly modeled in the UTCS1 program, the graphics program, in addition to generating the graphics, must augment the UTCS1 model to develop a rational turning behavior of the vehicles at intersections. The relation of these programs is shown in Figure 3.

A variety of traffic control techniques is illustrated in the film. Some intersections are controlled only by stop signs and some have fixed-cycle controllers. The intersection at New York Avenue and Main Street has an actuated signal with traffic passage detectors located 15.2 m (50 ft) from the intersection on New York Avenue and left-turn presence detectors located in the left-turn pockets on Main Street. The signal cycle for phases A and B is given below.

Phase A	Phase B
Advance green (may be actuated)	Green
Green (30-s minimum)	Amber (3 s)
Lagging green (red)	All red (2 s)
Amber after lagging green	
Amber (3 s)	
All red (2 s)	

A comprehensive documentation film using this film technique would also demonstrate the effect of variation of parameters on intersection behavior. Therefore, the user could obtain an intuitive feel for the significance and sensitivity of these parameter settings. A number of sensitivity tests that could be used for this purpose and that were performed during the validation of the model are described in the users manuals. These tests use star and linear networks to illustrate the effects of signal (cycle length), flow rates, pedestrian movements, speeds, traffic mix, and signal offsets. In addition to the demonstration of signalization concepts, the film technique can also be used to demonstrate dedicated lane and street concepts and bus priority systems that are of current interest.

Figure 3. Development process for simulation film.

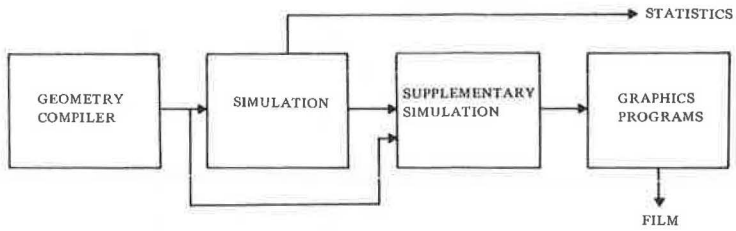


Figure 4. Movement area concept demonstration.

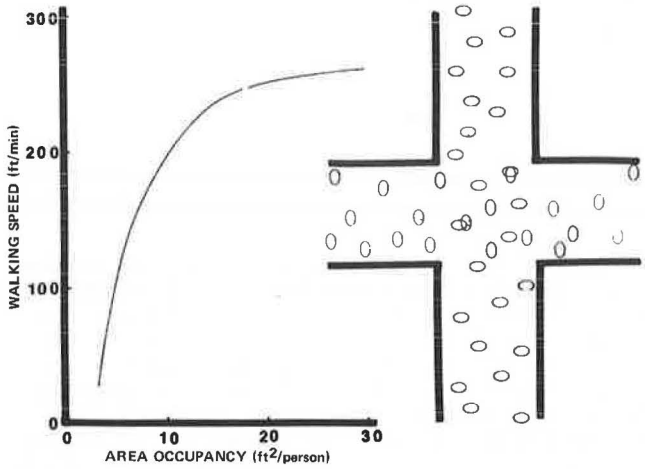


Figure 5. Service device concept demonstration.

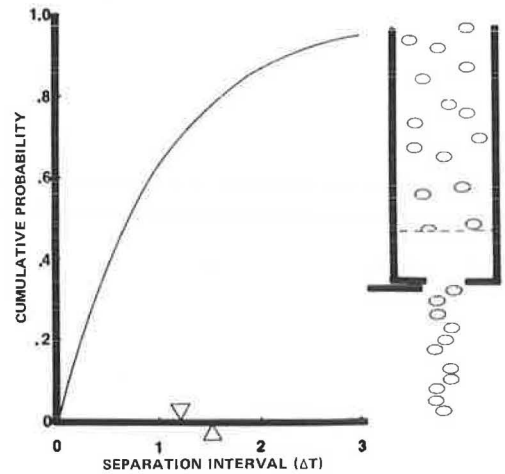
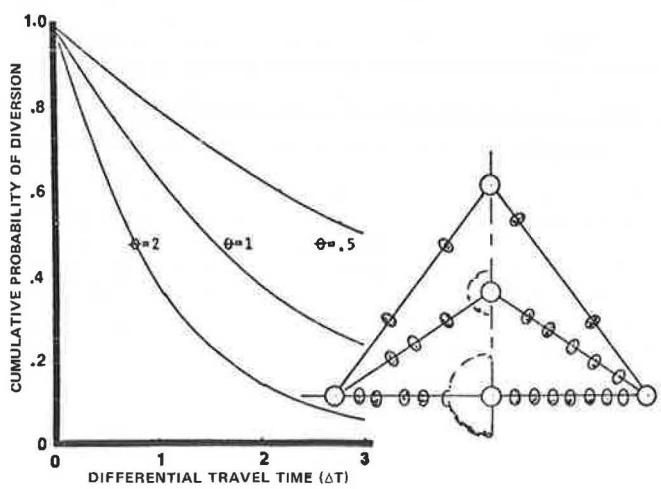


Figure 6. Path selection concept demonstration.



TRANSIT STATION SIMULATION MODEL

Another simulation model that is available from the Urban Mass Transportation Administration is the Transit Station Simulation Model (1, 2). This model has been developed to provide architects and transportation system planners with a tool that is capable of evaluating the alternative transit station designs with respect to pedestrian flow and processing requirements. Pedestrian flow dynamics are of particular significance for transit stations because of the high volumes of pedestrians that must be processed and the transient loading characteristics that result from the discrete nature of transit vehicle arrivals and departures.

Through the use of this simulation model, the transit station designer will be able to experiment with different system configurations, number of fare collection gates, number of escalators, and the sizing of stairways and platforms. This experimentation will enable the designer to arrive at the most cost-effective design while maintaining high standards of pedestrian safety and comfort over the full range of anticipated variation in passenger and vehicle loading.

The simulation model incorporates a rather generalized concept through which submodels provide for the basic elements of the system. These elements are assembled by the user to represent a complete transit station or any other pedestrian-processing type of system. Although this generality is desirable, it does require user sophistication in the area of modeling concepts and a detailed understanding of the operation of the individual modeling elements. These qualifications are necessary for translating real-world features into the abstract model formulation and for interpreting the results obtained.

The users manuals and program documentation that have been developed will provide the ultimate reference source for the user. However, these documents may not be the most effective means for apprising the potential users of the existence and nature of the model or for explaining the dynamic characteristics of the model elements and the relation of these elements to their real-world counterparts.

The transit station simulation model, like the UTCS1 model, is microscopic in nature with each pedestrian and vehicle modeled individually. In addition to these moving entities the simulation world view is comprised of three basic elements:

1. Movement areas (links),
2. Service devices (nodes), and
3. Path selection mechanisms.

To use the model effectively, the user must under-

stand thoroughly the operation of these elements and the effect of their parameter settings on system operation. This understanding is necessary for the user to assemble the elements into a network that represents an actual transit station (corridors, lobbies, fare collection devices, escalators, and platforms).

By showing the dynamic operation of each type of element individually and the variation of its parameters in a computer-generated film, an intuitive understanding of the model can be developed. The pictorial representation used to illustrate the three elements in the film is shown in Figures 4 through 6.

Figure 4 demonstrates how the walking speed of each pedestrian is selected at random with the mean speed a function of the congestion of the movement area (square feet per person) (6). (SI units are not given for the variables in this model inasmuch as its operation was developed in U.S. customary units.) Pedestrians moving vertically in the diagram are shown in green, and pedestrians moving horizontally are shown in red. The incidence of conflicts is shown by overlapping areas of the individual figure in yellow. On the right side of the screen, the functional relations between average speed and area occupancy are shown in coordinated colors since these parameters are varied.

Figure 5 shows the format for the film segment on service devices such as fare collection gates that are represented as nodes in the simulation. This sequence illustrates that (a) the queue provides high-density storage of pedestrians, (b) the service device can be activated by doors, (c) the mean processing rate of the service device and the spacing between pedestrians leaving the device are controlled by a statistical distribution function, and (d) the queue buildup depends primarily on the relative means of arrival and departure service time distributions.

The probability distribution function for the device is plotted against time interval on the right of the screen. The path selection mechanism incorporated in the model is based on a model described by Dial (7). This model distributes pedestrians over reasonable paths as an inverse function of the travel time for the path. A parameter (θ) must be set by the user to adjust diversion sensitivity to differential travel time.

Figure 6 shows the format used in the film to show the operation of the concept and the effect of this parameter setting in a simple five-node, six-link network. Pedestrians are shown by the moving ellipses and the queues are shown by shaded concentric semicircles at the three service device nodes, which are intermediate between the diversion node and the destination. At low pedestrian flows or low values of θ, most of the flow is along the shortest path from origin to destination. As either one of these increases and as the queue length (travel line) along the direct path increases, the flow will divert to other routes.

After the user has been introduced to the operation of the individual elements of the model in the manner described in this paper, a case study can be presented that shows how a network of these elements can represent an existing or planned transit station. In this case study, the passenger demand rates, transit vehicle headways, transit vehicle sizes, number of service devices (such as escalators), and other features can be varied to show how alternative designs would be investigated by using the model.

Other applications of computer graphics to the planning of transportation systems that may be of interest to the reader are reviewed elsewhere (8, 9).

CONCLUSION

The use of simulation models has been shown to be an effective technique for designing new and complex urban transportation systems. However, the use of sophisticated tools such as these has been constrained by the complexity of the models. Better means are therefore needed to disseminate information about the models and about user training. The use of computer-generated films that show the dynamics of model operation can be a valuable aid in this process.

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Sacramento Car-Pool Project: Interim Evaluation Report

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This paper describes and evaluates a government program whose purpose is to obtain knowledge about and demonstrate the practicality of car pooling as a means of conserving fuel, improving air quality, and reducing transportation costs by better use of vehicles and existing transportation facilities. The program accomplishes this purpose by promoting the voluntary formation of car pools. The paper also addresses (a) the public benefits that result from car-pool matching projects, (b) the dollar benefits to participants in such projects, and (c) the costs to provide the benefits. Many insights into the conditions, practices, and natures of participants that lead to successful car-pooling efforts are furnished, and a conclusion is reached that a cost-benefit ratio of 14.7:1 can be achieved.

How can governmental agencies improve transportation? One way is to decrease the amount of traffic on the road by moving the same number of persons in fewer vehicles. This process of increasing the average vehicle occupancies can be accomplished in many ways. Some examples include exclusive bus and car-pool lanes, preferential treatment for parking facilities, priority entrances at freeway on-ramps, higher gasoline prices, rationing, and flexible working hours. One governmental program that increases vehicle occupancy rates on a voluntary basis is a matching service that lists or matches neighboring commuters to assist them in joining car pools. The Sacramento Car-Pool Project initiated such a matching service on July 1, 1974.

The purpose of this paper is to describe the results of the first 8 months of the Sacramento project. The evaluation addresses three basic questions.

1. What are the public benefits that result from car-pool matching projects?
2. What are the dollar benefits to participants in such projects?
3. What does it cost to provide the benefits?

Findings about factors that contribute to the successful implementation of areawide car-pool matching projects are also documented.

The basic purposes of the project are to obtain knowledge and demonstrate practices related to conservation of fuel, improvement of air quality, and reduction of transportation costs by better use of vehicles and existing transportation facilities. The U.S. Department of Transportation, the California Department of Transportation, the city of Sacramento, and Sacramento County jointly initiated the Sacramento project on July 1, 1974. The effort called for an expenditure of $150 000 over an 18-month period. The county sponsored the effort by allocating $135 000 of its federal-aid urban system funds and by sharing the 10 percent matching requirements equally with the city and the state. During the first 8 months of the project $55 663 were expended.

The city and state act as consultants to the county in implementing the project: The state furnishes the matching portion of the effort, and the city implements a system of preferential parking rates in its central area parking facilities.

The project provides matching assistance through both the organizational services and dial-in programs. The organizational services element of the project is directed toward establishing a large clientele of car-pool participants by working through the larger employers of the region. This service is used to rapidly build a data base of interested persons from which matching lists can be established, and it also provides a source of names to be used in assisting those who seek help through the dial-in service.

In Sacramento, most of the large employers are associated with government. Since the state capitol is located in the central city, the headquarters offices of most state agencies are also located in the downtown area. Many federal, county, and city offices are also located in the core area. Approximately 50 000 people commute to this central area each weekday. Although the metropolitan area is comprised of approximately 750 000 people, heavy industry does not predominate. Rice, tomatoes, melons, and other agricultural products generate rapid buildups and cutbacks in the work force. Thus, this situation does not facilitate the task of creating car pools.

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Although the matching element of the organizational services provides an opportunity to rapidly build a data base, the project staff recognized that many of the persons who most needed car-pooling assistance were employees of smaller companies. Furthermore, an estimated 40 percent of the 110 000 workers of the region are employed in organizations with fewer than 200 workers. The dial-in service was established to respond to the needs of this user group. Without the use of dial-in service, it would have been impossible to establish an integrated system that provides a complete service and meets the needs of all of the potential car-pool participants of the region. Furthermore, the car-pool office, with its easily remembered telephone number (445-POOL), serves as a coordinating unit for all car-pooling, van-pooling, and bus-pooling efforts in the region, whether the pooling efforts are a part of the Sacramento project or not.

The three largest nonstate employers in the region are two air force bases and the Aerojet General Corporation. There are 18 000 people working at McClellan Air Force Base, 7 000 working at Mather Air Force Base, and 2700 working at Aerojet. The two air force bases have their own computer-matching services but frequently coordinate with the project staff in seeking poolers for special situations such as long-distance commuting.

The Sacramento project personnel assisted McClellan Air Force Base in developing their system, but research for this paper does not include data from either McClellan or Mather Air Force bases. The aerojet facility did not become a part of the Sacramento project until July 1975; thus, the results from these matching efforts are not included in this study.

ORGANIZATIONAL SERVICES

Both the organizational services and the dial-in system stimulate car pooling by soliciting prospects and by giving them the necessary information to find ride-sharing partners. The organizational services program solicits prospects indirectly through the large employers in the region. The project staff initially contacted company personnel officers who provided direct assistance or an introduction to an appropriate manager. The employers were generally cooperative since their time and money expenditures were insignificant, and the program created a sense of good will with employees. Upon employer agreement to participate in the project, the project staff supplied posters for display in prominent locations. These posters provided advance publicity for later organizational service efforts. Many firms have also given the matching service excellent advance promotion in their company newsletters.

In most cases, a company executive signs a letter addressed to all employees that is then reproduced by project staff along with appropriate informational fliers and applications for participation in the program. The applications request the name of the prospective car pooler, approximate home location, phone number, working hours, and means of commuting. These applications are distributed to all employees with the transmittal letter, and interested persons are requested to fill in the needed information and return the applications to a central collection point in the organization. The applications are then picked up by a project representative and delivered to the data processing center.

Keypunchers transcribe the information from the questionnaires onto tape for computer input. The computer then produces printed lists of prospective car poolers who have similar departure and destination points. Each prospective car pooler receives a list and is encouraged to use it to assist in forming a car pool. The computer program used is a modified version of the car-pool matching program of the Federal Highway Administration.

Since the inception of the organizational service two features have been changed. During the first few months of the project, all employees were requested to complete questionnaires whether they were interested in car pooling or not. This practice was discontinued after it became apparent that persons sincerely interested in starting car pools became discouraged when they contacted others on their matching lists who really did not care to be bothered.

The second feature that changed was the use of grid maps. At first, the maps were posted throughout employment areas. The maps divide the Sacramento area into 1.6-km (1-mile) squares. Participants were asked to provide both street address and grid coordinates on the applications. Finding the map posting locations that were easily accessible to all employees was time consuming and cumbersome. Inexperience in map reading frequently led to errors in coding. Under the current system, employees merely list major street intersections near their homes, and project personnel code the grid coordinates for machine entry. Private sector participation increased substantially after these two changes were made.

DIAL-IN SERVICE

The dial-in service was designed to make matching services available to the entire community. Access to the system is gained through phone calls by any prospective car pooler, regardless of the size or location of the car pooler's place of employment. When the potential car pooler phones the car-pool number, a receptionist completes the questionnaire and provides the names of all project participants from a master file. The file is periodically updated to show the names of people still interested in car pooling. Car-pool receptionists try to respond to dial-in requests within a maximum of three days and frequently create new car pools within a matter of hours when the need is urgent.

Sacramento has a large number of small employers dispersed throughout the metropolitan area. It would be impractical to contact each of these employers on an individual basis; therefore, various approaches were used to publicize the matching service of the project. For instance, significant but smaller work-center areas in the region were saturated with fliers and posters. Car-pool project staff appeared on news and talk show programs on radio and television. These shows provided good opportunities for promoting the dial-in service and for explaining both the community and individual benefits of car pooling.

Car-pool promotion spots were placed on three of the local radio stations with traffic airwatch programs. These programs provided commute-period traffic information directly from an airborne announcer to a large clientele. Other promotion was provided by advertisements in a local weekly newspaper and by billboard advertisements that were paid for in half by the League of Women Voters.

RESEARCH DATA

The evaluation study was begun after 6 months of project operation. At the conclusion of the study, the data were expanded to cover the first 8 months of operation. The primary purpose was to measure the goals achieved, fuel conserved, air quality improved, and transportation costs reduced. As each goal element corresponds to

vehicle-kilometer (vehicle-mile) reduction, it was necessary to determine the number of vehicle-kilometers (vehicle-miles) that were reduced by car pooling. Also required was the percentage of prospects who formed car pools as a result of project efforts. These data were obtained by interviewing the persons who applied for the matching service.

At the time of the survey, there were 5083 names in the organizational services data base. Standard statistical methods indicated that a sample size of 754 interviewees was appropriate for this population. It was assumed that 15 percent of the applicants had joined car pools. A random process was used to select the actual interviewees, and interviewers contacted approximately 84 percent of the sample population. At the end of the 8-month period, the organizational services data base had grown to 6225 prospects. Survey findings were extrapolated to this number.

After 6 months, 573 prospects had contacted the program through the dial-in service. The prospects who were supplied names of potential ride-sharing partners through dial-in were requested to inform the car-pool office of their successes in forming car pools. Consequently, it was known that 254 of the 573 callers had formed car pools, a success rate of 44 percent. Of the 254 successful applicants, 92 applicants (36 percent) were interviewed as a sample population. At the end of 8 months, 372 of 998 dial-in prospects or 37 percent of the applicants had been placed in car pools.

Table 1 gives the data from these interviews. The most significant items of information are described below.

1. Of those interviewed, 21.8 percent were placed in car pools (37 percent from dial-in services and 19.3 percent from organizational services);
2. Of those placed, only 15.2 percent dropped out during the study period (10.9 percent from dial-in services and 18.5 percent from organizational services);
3. Those who did drop out remained in car pools for an average of 16.6 weeks before leaving the car pool (8.2 weeks for dial-in services and 20.4 weeks for organizational services), and the most common reason given for dropping out was change in work situation;
4. Weekly kilometer savings by users of the system averaged 143.2 km (89.0 miles) [187.3 km (112.4 miles) for dial-in services and 128.4 km (77.1 miles) for organizational services]; and
5. Of those interviewed, 76 percent said that their vehicles for commuting were not used on days they did not drive (72 percent for dial-in services and 78 percent for organizational services).

The other significant survey findings not given in Table 1 are

1. The trend by car poolers toward the use of smaller sized cars was 27 percent for subcompacts, 14 percent for compacts, and 59 percent for conventional sized cars;
2. Most car poolers (57 percent) had previously driven alone or were in another car pool (33 percent), but few (7 percent) were diverted from transit, i.e., Sacramento Regional Transit bus service;
3. There were 2.15 drivers and 1.98 automobiles in the households in which vehicles for commuting were idle. There were 2.41 drivers and 1.66 automobiles in the households in which vehicles for commuting were not idle; and
4. The average occupancy for each car pool was 3.2 persons.

Figure 1 shows the distribution of car pools by daily one-way commute distance. Figure 2 shows the distribution of poolers by weekly decreases (or increases) in commute-kilometers driven. An increase occurs when a car pooler who drives or shares driving was formerly a rider only or a commuter by transit.

ANALYSIS OF DATA

The data obtained were used to determine the dollar value of public benefits that resulted from the car-pool program and to measure program effectiveness. It is possible to estimate the savings to the individual consumers (the commuters who become car poolers). The savings for individual consumers are a direct function of the reduced vehicle-kilometers for their personal automobiles.

The consumer's cost of operating an automobile is 7.0 cents/km (11.2 cents/mile) for a subcompact, 8.0 cents/km (12.9 cents/mile) for a compact, and 9.9 cents/km (15.9 cents/mile) for a conventional size automobile. For the Sacramento project, these costs were adjusted to correspond to the mix of car sizes used by the surveyed car poolers. The operating cost for car poolers in the project [8.8 cents/km (14.2 cents/mile)] represents the car-pool vehicle.

The dollar value of savings to individual users is $818 400/year [8.8 cents/km (14.2 cents/mile) × 9 300 000 km (5 766 500 miles) of reduced vehicle travel]. After establishing this value for consumer benefits, the question of cost to provide the savings was addressed. Analysis of cost-accounting records for the project indicated expenditures totaling $55 663 for the first 8 months of the effort. The return for the first year was $818 400; the rate of return was 1470 percent. Thus, the project has a 14.7:1 benefit to cost ratio for individual users plus an unquantifiable value of benefits to the general public.

To arrive at the 14.7:1 ratio we assumed that the life of a car pool is 1 year. This assumption appears conservative since car pools tend to perpetuate themselves; when one member drops out, the remaining members seek a replacement. It is not difficult to interest a significant proportion of commuters in car pooling. After 8 months, the dial-in service had generated 998 prospects and the organizational service had generated 6225 prospects, a total of 7223 prospects. This total is approximately 1 percent of the population of the Sacramento metropolitan region.

A significant proportion of inquiring commuters were motivated to join and stay in car pools. Overall, 21.8 percent of the prospects joined car pools (37 percent of the dial-in prospects and 19.3 percent of the organizational service prospects). There were few dropouts: Only 11 percent of the dial-in service and 18.5 percent of the organizational service customers placed in car pools discontinued car pooling. The cost to place a commuter in a car pool is low compared to the benefits derived. Of the 372 dial-in prospects (actual count) and the 1201 organizational service prospects (extrapolated), a total of 1573 were placed in car pools during the 8-month period. The total cost was $55 663, and the cost for each prospect placed was $35. Comparisons with other car-pool programs indicate that the $35 placement rate is very competitive.

Benefits to the general public are given in Table 2, and a dollar value was not assigned to them. Table 2 is based on data (1) for a 1970 automobile that was the typical model according to the survey. The 14.7:1 benefit-cost ratio applies to user advantages only. The general public benefits are described in greater detail below.

1. Transportation facilities are designed to provide capacity for peak commuting periods. Any reduction in use of vehicles by commuters directly affects the traffic flow during the peak period and reduces the highway facilities needed. The car-pool project reduced the facility needs by 9 280 300 vehicle-km (5 772 346 vehicle-miles) of travel per year during peak commuting hours. There is a corresponding increase of efficient commuter traffic flow that resulted in savings of time and fuel.

2. Many of the dollars previously spent for fuel are now available for the purchase of manufactured goods, which acts to stimulate the economy. Reduced fuel import requirements help the country's balance of payments. The reduced use of fuel will prolong the life of one of our valuable natural resources.

3. Although figures for industrial and governmental costs in reducing pollutants are not readily available, it is felt that they are significant. All reductions in pollutants will help to attain state, federal, and local goals of improving air quality.

4. The use of central area land for storage of idle vehicles is not a highly productive use of the land. However, because of the parking needs generated by the commuters'

Table 1. Survey data.

Item	Dial-In Service	Organizational Service	Combined Total
Persons interviewed	92	615	707
Interviewees placed in car pools	92	119	211
Interviewees placed and later dropped out	10	22	32
Interviewees placed, percent	37	19.3	21.8
Interviewees placed and later dropped out, percent	10.9	18.5	15.2
Average length of participation for dropouts, weeks	8.2	20.4	16.6
Average one-way commute, kilometers	36.2	27.4	29.6
Commuting kilometers reduced per week per car pooler	221.6	141.8	161.9
Increased home use kilometers per week per car pooler	34.3	13.4	18.7
Net kilometers saved per car pooler	187.3	128.4	143.2
Average annual kilometer savings per car pooler[a]	8610	5905	6589
Cars idle when not used for commuting, percent	72	78	76

[a] In converting weekly kilometer savings to annual savings (46 weeks), an allowance of 6 weeks was made for vacation, sick leave, and days when automobile must be driven for personal reasons.

Figure 1. One-way distance to work.

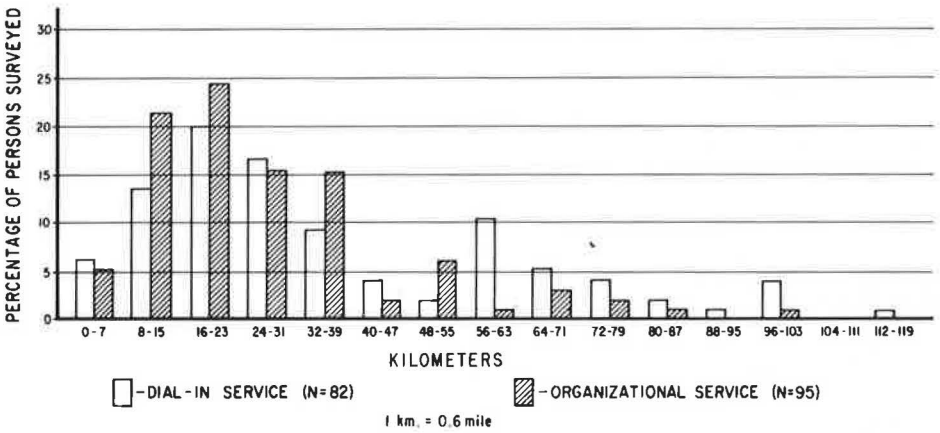

Figure 2. Difference in distance driven per week due to car pooling.

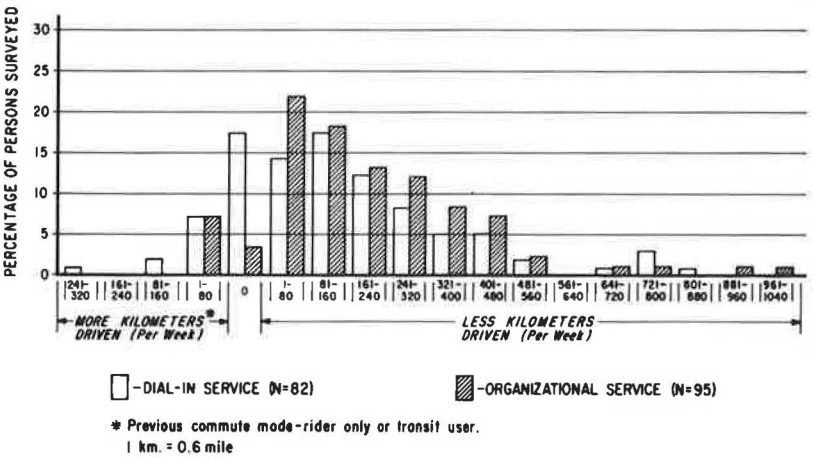

Table 2. Public benefits.

Item	Amount
Reduced travel, vehicle-km/year[a]	9 280 300
Conserved fuel, L/year[b]	1 679 200
Reduced pollutants, kg/year	
Carbon monoxide	156 900
Oxides of nitrogen	31 400
Hydrocarbons	26 200
Total	214 500
Reduced parking needs, spaces[c]	600

Note: 1 km = 0.6 mile; 1 L = 0.2 gal; and 1 kg = 2.2 lb.

[a] Extrapolated from survey results.
[b] Assuming 21 km/L.
[c] Assuming 1.3 and 3.2 persons/vehicle before and after pooling respectively.

use of automobiles, most cities have found it necessary to require property owners to provide parking for employees and customers. The parking facilities designed to economize on land use require approximately 18.6 m^2 (200 ft^2)/parking space, including driving lanes. Consequently, the reduction of 600 parking spaces created by the project is equal to 12 138 m^2 (3 acres) of expensive downtown land.

CONCLUSIONS

A number of conclusions can be drawn from the research. It is acknowledged that conditions may differ in other locales; however, we believe that the conclusions drawn may serve as guidelines for those who plan car-pool projects in other typical metropolitan regions.

1. Car-pooling projects can be used as cost-effective methods for reducing commuter transportation costs. User benefits to cost ratios of 14.7:1 are attainable.
2. Both dial-in and organizational services must be provided if all of the potential car poolers of the region are to be appropriately served.
3. Expenditures can be held to approximately $35/person placed.
4. The average person placed reduces the use of his or her personal automobile by about 6400 km (4000 miles)/year.
5. Of the commuting car poolers, 72 percent do not use their vehicles on days when they are not required for car-pool travel.
6. Most car poolers placed are taken from single-occupant vehicles (57 percent) or smaller car pools (37 percent).
7. If a good transit service is provided such as in Sacramento, a low percentage (7 percent) of new car poolers are drawn from transit.
8. A large percentage of car poolers drive small vehicles (27 percent for subcompacts, 14 percent for compacts, and 59 percent for standard size).
9. Large expenditures for advertising and other forms of promotion are not required to motivate substantial numbers of commuters to join car pools: Of the total $55 663 expended, only $4000 was spent on the promotion of car pools.

REFERENCE

1. Compilation of Air Pollutant Emission Factors. U.S. Environmental Protection Agency, Feb. 1972.

Urban Transportation Planning System: Philosophy and Function

Robert B. Dial, Urban Mass Transportation Administration, U.S. Department of Transportation

This paper describes the philosophy behind and the functional requirements of a computer-based system for urban transportation planning. It begins with a view of the current transportation problem and the resulting new demands on the planner. After outlining a planning framework composed of three analytical activities, long-range planning, short-range planning, and system surveillance, it outlines the functions of a software system, the Urban Transportation Planning System, that would effectively support the transportation planner of today. Such a system is presently under development at the Urban Mass Transportation Administration.

Sometime in the 1950s a certain Hudson Valley transportation planner, a direct descendant and namesake of Rip Van Winkle, dozed off over his drawing board to sleep for the traditional 20 years. While this latter-day Van Winkle dreamed his unimodal dreams, undisturbed by social and environmental nightmares and unaware of energy crises, his more lively colleagues slaved away.

On awakening in the 1970s, he sleepily looked out of his office window and immediately perceived the apparent ineptitude of his old colleagues. It was obvious that while Van Winkle had slept, Americans had invested trillions of dollars in automobiles, roads, parking facilities, traffic signals, policemen, traffic courts, hospitals, insurance companies, tire factories, oil industries, drive-ins, and billboards—all in deference to the private automobile and highway system. Yet in spite of this enormous capital expenditure, congestion still paralyzed the cities, which smelled awful and looked worse than they had 20 years before.

Coming to their own defense, his fellow planners argued that they should not be faulted for the current state of affairs. They had been misguided in their ignorance of the issues. No one had urged them to consider costs and benefits except those who had supported the popular demands for more cars and more roads. They had lacked both the technical and fiscal wherewithal to plan, much less to build, for anything but the automobile.

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It was not until the 1960s that the planners had admitted that urban man does not move by car alone and that transit is also necessary. Like an aged football player abruptly recalled from retirement to substitute for the limping superstar, public transportation was dusted off, given an aspirin, and sent into the dying seconds of the game. Renamed mass transportation (perhaps to connote the movement of slugs rather than people), it was ordered to reduce congestion so that automobiles might go faster. With less than 1 percent of the capital budget spent on the automobile and highway system, it was asked to solve the problems of the automobile as well as those that the automobile had caused. And to make matters worse, it was given no federal subsidy for operation.

After Van Winkle rubbed the sleep from his eyes, he dutifully examined the records for the 20 years of his nap. Something of a student of human nature and of history, and now with the freshest mind in the business, he was neither surprised nor alarmed by the misconceptions or the misdirections. He regretted the waste of time, money, and talent, but he understood it in terms of the political economy and was not disposed to judge it harshly.

Van Winkle was most disappointed to see that the present planning procedures differed so little from those he had been using when he dozed off. He saw that the technical expertise needed to solve problems (problems unknown in the 1950s) had increased by an order of magnitude. It was immediately clear to him that he would need new methods to deal with ideas that he had never heard of priority lanes, congestion pricing, dial-a-ride, personal rapid transit, environmental impact statements, energy conservation, quality of life, Urban Mass Transportation Administration (UMTA) capital grants, and others. The problems were new and the ground rules for their solutions had changed, but Rip saw that the present-day tool kits held the same tools that had rusted to pieces in his battered old box as he slept.

We must now let our brave old friend, and our newly awakened planner, go back to work. We should acknowledge our debt to Van Winkle's perspective as we begin to describe the current concerns and goals of UMTA. That historical perspective is very important to us, as UMTA research and development begin

to reflect the recent federal awareness of the very different planning problems of a new era with new complexities.

LESSONS LEARNED

Certainly there are four lessons that Van Winkle's experience teaches us, and we must learn them with him if future transportation planning is to be successful and save our urban transportation systems from inexorable decay.

The first lesson is that the transportation problem can be solved only at the local level. It is apparent that the problem was made worse by the federal tilt toward highways during the last 20 years and by federal policies that earmark funds for specific modes, regardless of local needs and desires, which aggravates rather than ameliorates the situation. Any effective solution will probably require a better use of the automobile as well as vastly improved public transportation.

The second lesson is that we must make better use of the transportation resources that we have and not automatically assume, in response to a problem, that what we need is more. Our superb highway system is 50 percent underused about 90 percent of the time. Too often roads are conceived of as providing for the movement of cars and trucks, rather than of people and goods, while in fact at certain times it is advantageous to ban cars and trucks from some segments of the road system. Public transportation passengers, pedestrians, and cyclists should receive much higher priority in the planner's mind and on the city's streets.

The third lesson is that urban transportation planning, implementation, and operation must be coordinated without an artificial administrative and jurisdictional partitioning of functions and responsibilities. Planners must guide builders. Operators must trust planners. Planners must be informed by builders and operators. In the past, these people scarcely knew one another, but today they must work together.

The fourth lesson is that the planner must consider a much larger set of options and issues. He must look for more and better transportation alternatives. The evaluations of these alternatives will, in large measure, be based on nontransportation issues. Not only are the problems of today more acute, but also the constraints on feasible solutions are tighter. More technical expertise is required.

Today, the planner must plan a system, not merely design appendages to growing freeways. He now must justify his recommendations with lengthy alternative analyses and examine vastly different and sometimes radical proposals. He must describe and defend the numerous potential impacts of a proposed plan to impatient politicians, a vociferous press, and a suspicious public whose questions are selfish, diverse, and microscopic. A decision to build will never again be based on a simplistic travel time measure. Many other criteria, often conflicting, must be addressed.

NEEDED: IMPROVED PLANNING TOOLS

Since Van Winkle refuses to give up despite the staggering problems of urban transportation, the least we can do is help him to replace his rusty tools. And as we awaken with him into a new era of transportation planning, his clear view of the stunning differences between the 1950s and the 1970s can help us decide what kinds of tools are needed.

The traditional planning techniques now in common use are slow and costly: slow because they use a hunt-and-peck system to find a good plan, and costly because of long turnaround times and high data costs. Their most serious weakness is their inability to evaluate multimodal planning alternatives accurately and responsively. At best, they plan effectively for one mode, the private automobile.

Local planners are keenly aware of these shortcomings. They must respond quickly to local policy questions. Despite their inadequate resources, they must proceed and plan with what they have. Piecemeal efforts of local planning agencies to improve tools often cost more than their marginal success is worth. The federal government's research and development of improved planning techniques will be especially valuable and welcome at the local level.

UMTA RESPONSES AND PLANNING PHILOSOPHY

For as many years as there have been large computers available, state and local agencies have used them for planning. UMTA research and development can help local planners best by packaging for their use the best research and development products in computer software. In this way UMTA can require local planning to improve and can provide the technical and fiscal support for that improvement.

Accordingly, in 1972, the UMTA Office of Research and Development began a program to

1. Research and develop improved planning techniques,
2. Implement these techniques in generalized computer software,
3. Pilot test software in urban areas to ensure its appropriateness and demonstrate its utility,
4. Distribute the software to local planners, and
5. Provide technical backup by training users and responding to queries from the field.

The result of this program will be the Urban Transportation Planning System (UTPS). UTPS is a package of computer programs for site-specific planning of multimodal transportation systems. The package is evolutionary and is being constantly enlarged and updated. Its ultimate goal is a streamlined, easy-to-use set of modular tools applicable to several planning activities.

Two considerations affect the design of UTPS. First, variations in local issues and resources create many different planning situations, and no one model fits them all. Second, to be easy to use and yet adequately sophisticated, the technical complexity must in large measure be invisible to the user.

To accommodate the variety of planning situations, UTPS distinguishes three overlapping, sequential, and iterative planning activities: long-range planning, short-range planning, and system surveillance (as shown in Figure 1). The first provides a context for the second; the second precedes implementation; and the third monitors performance to feed information back to the first two. Each is discussed below.

Long-Range Planning

There are two types of long-range planning. One searches for a strategy and the other articulates in some detail a design within a selected strategy. These are called strategic (or sketch) planning and tactical planning (Figure 2). Both involve both manual and computerized processes. Where computerized, each entails the design, coding (for computer consumption), evaluation, debugging, and improvement of a transportation system concept (Figure 3).

Sketch planning is the preliminary screening of possible multimodal configurations or concepts with varying assumptions as to alternative futures. It is an aggregate, multivariate system evaluator and comparer. It is especially necessary for long-range regional planning (10 to 20 years), and at minimum data costs gives preliminary estimates of the capital and operating costs, patronage, wide corridor-traffic flows (by mode), service levels, and land development implications of possible multimodal networks. It also estimates such factors as energy consumption and air pollution. It compares all these data with those available about other networks and provides the information needed for broad policy decisions.

The demands on such a strategic model for long-range planning are challenging. First, it must make it very easy and fast to evaluate credibly an alternative strategy. The far future options are limitless, scores of them must be considered, and thus each must be done quickly. Second, the model must be able to simulate the performance of modes that are as yet unspecified. Third, it must deal explicitly with uncertainty. Two of the most difficult uncertainties are those associated with socioeconomic and land developments, and those associated with the costs and performances of new transportation technologies.

Figure 1. Planning process.

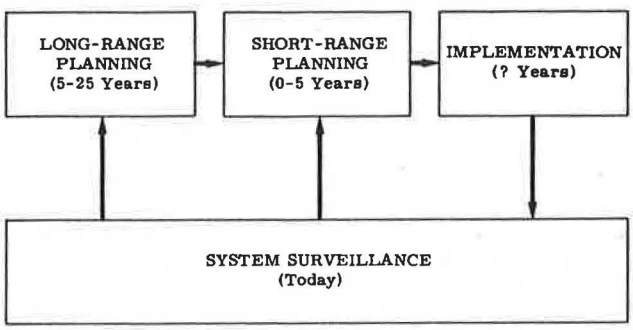


Figure 2. Planning types.

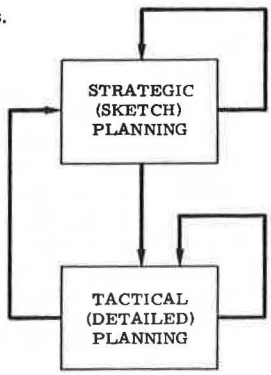
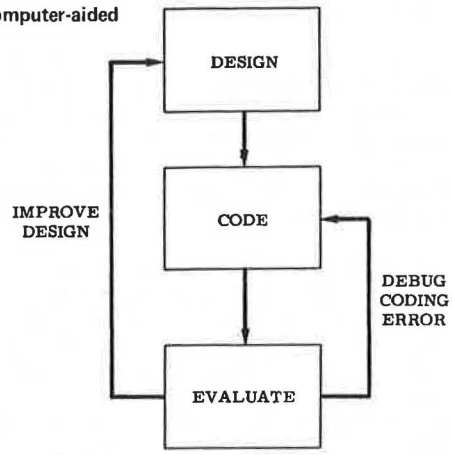


Figure 3. Computer-aided design.



Sketch-planning input is characterized by a small (less than 800 nodes) but rich abstraction of an (abstract) multimodal network. By using highly aggregated measures, it compares a large number of proposed policies in just sufficient analytical detail to support strategic decisions. Trip generation, distribution, modal split, and assignment—traditionally four different technical steps—are handled in a single step. Supply versus demand equilibria are explicitly considered. Outputs are related directly to issues. A single system alternative is evaluated at less than 10 percent of the cost of existing long-range planning techniques.

The planner remains in the sketch-planning mode until he or she completes his comparisons of possibilities or finds a strategic plan worthy of consideration at the tactical level.

Tactical planning treats the details appropriate to midrange (5 to 10 years) planning and identifies the best configurations within a given strategic concept uncovered in the sketch-planning phase. The input and analytical techniques are close to those of the state-of-the-art regional and corridor-planning studies of today. Inputs include the location of principal highway facilities and delineated transit routes. These feed a network model that addresses any automobile versus transit vehicle interaction. Disaggregate demand forecasting techniques are applicable here.

In contrast to sketch planning, tactical planning can provide disaggregated cost and benefit measures that relate more accurately to the citizens and resources affected. At this level of analysis the outputs are estimates of transit fleet size and operating requirements for specific service areas, refined cost and patronage forecasts, level-of-service measures for specific geographical areas, and where necessary, a program for staged implementation. Household displacements, noise, localized pollution, and aesthetic factors can also be evaluated.

The cost of examining an alternative in midrange planning is 10 to 20 times its cost in sketch planning, although default models, which assume away certain data requirements, may be run for a relatively inexpensive first look. Apparently promising plans can be analyzed in further detail, and problems uncovered at this stage may suggest a return to sketch planning to accommodate new restraints.

Short-Range Planning

As in long-range planning, there are two distinct types of short-range planning activities. One is the quick evaluation of broad, areawide transportation strategies, and the other is the preparation of a detailed delineation of an optimal system design reflecting a given strategy. In the former, the difference from long-range strategic planning is that the short-range case requires more accurate cost versus benefit estimates, but fortunately greatly improved accuracy is obtainable. In contrast to the long range, the feasible transportation options in the short range are very limited, and the costs and capabilities of individual system components are accurately known. In addition, in the short range, human behavior and demand for transportation are less difficult to forecast. Thus, a much more precise evaluation is possible. Some examples of the kinds of policies a short-range

strategic model can address are (a) areawide dial-a-ride service, (b) widespread designation of automobile-free zones, (c) road-user taxes or increased gasoline taxes, (d) order of magnitude increases in transit fleet size or exclusive guideway (lanes), and (e) broad changes in parking policy.

Detailed delineation of the plan and the expected costs and benefits of the system are required prior to a final decision to implement. The outputs of long-range tactical planning models and short-range strategic models are usually too abstract for engineering design purposes, but as the time to implement projects draws near (5 days to 5 years) detailed simulations can be used to refine design parameters. Some examples of activities at this stage are

1. Detailed evaluation of the extension, rescheduling, or repricing of existing bus service;
2. Simulation of bus priority lanes or signal systems;
3. Analysis of passenger and vehicle flows through a transportation terminal or activity center; and
4. Comparison of possible routing and shuttling strategies for a demand-activated system.

Analysis at this detailed level can be prohibitively expensive except for subsystems whose implementation is highly probable and in which such design refinements bring substantial increases in service or significant reductions of cost or uncertainty. It is effective in planning only when the large number of exogenous variables can be accurately observed or estimated.

Surveillance

Besides permitting a continual scrutiny and evaluation of transportation services, performance, costs, and use, the data from a good surveillance program support near-term planning to eliminate problems such as overloaded links, inadequate transportation opportunity, and the underuse of existing resources. Knowledge of the current state of affairs is a prerequisite to any planning. It is essential that existing highway and transit systems and their users and the environment be monitored to ascertain the service provided, to whom, and at what cost. Such data are needed for supply-and-demand model verification and calibration as well as for system evaluation. In addition to the traditional traffic counting, user-oriented surveys of such things as convenience and travel time must also be maintained. Information about the citizen's travel patterns and socioeconomic attributes are also needed.

The development of good short-range planning and surveillance tools brings the greatest return for the model-development dollar. This is especially true because the strong tradition of pure highway planning, which is preoccupied with long-range, capital-intensive programs, is of little help in the evaluation of immediate-action programs. Short-range planning requires the tools and analytical techniques that are needed to evaluate and to optimize the use of a city's existing transportation resources, and the development of these tools has high priority at UMTA.

UTPS FUNCTIONAL CHARACTERISTICS

To support the planner in the four stages identified above, UTPS acts as a highly interactive system that uses time-shared computers with on-line graphics terminals and is vastly different from the present slow-motion, error-prone batch operations. Interactive browsing through network and land use data, both digital and graphic, speeds up the planner's evaluations. Maps, charts, and graphs replace the millions of numbers that now overwhelm him. Graphic input via an electronic tablet speeds his data entry and run setup. An interactive network design model allows him to specify or to modify his plan virtually instantaneously. Many analytical processes are run while the planner waits at the cathode ray tube, which gives instant turnaround. To guarantee successful execution, longer analyses that require batch processing are dry run interactively before submission. Later the planner interactively browses through the outputs of the batch process.

The UTPS program library includes data-management routines, graphics routines, algorithms for statistical and mathematical programming packages, and specific planning models, all of the software needed to examine transportation supply and demand at each of the three planning levels described above. UTPS modules meet uniform software design standards, and adherence to those standards allows UTPS to add new software and provide improved analytical techniques as they become available.

Among the most important modules are those for system evaluation, demand estimation, network aggregation, data acquisition, and data management.

System Evaluation

The system evaluation tool is an open-ended set of analytical reports and graphics selected for the use of local planners, who may also include their own processes and reports on local issues. UMTA adds new reports as national issues arise. Local planners can compare significantly different network conceptions and make detailed analyses of the minor perturbations of a given network. They can evaluate present and proposed systems according to current and future demands. The other modules described below also directly support system evaluation.

Demand Estimation

Planners making demand estimates may choose from three kinds of models: off-the-shelf default models for local use without site-specific parameter estimates, default models with locally calibrated parameters, and user-made models that can be integrated into existing modules with little programming effort.

Algorithms for establishing supply-and-demand equilibria provide the capacity to determine route and mode selection equilibrium, origin-destination demand equilibrium, and land development-transportation equilibrium. The software supports the development, calibration, and application of both aggregate and disaggregate models.

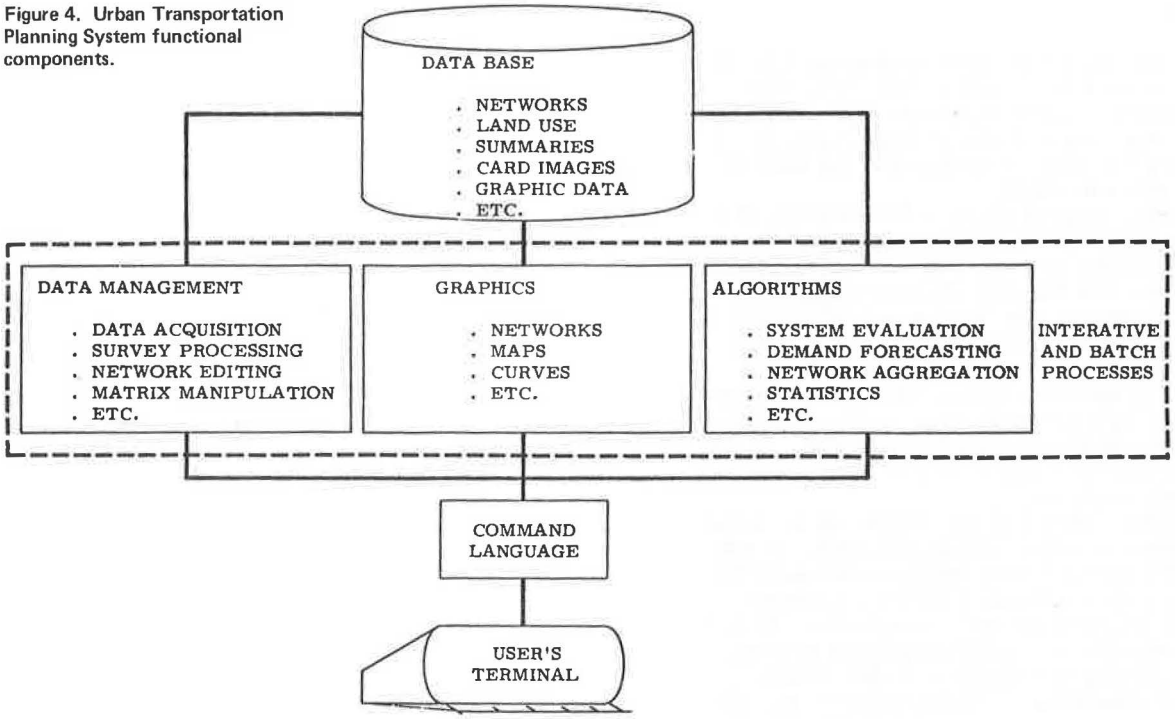
Network Aggregation Models

Among the improved tools being researched are the network aggregation models that are useful at all levels of planning. The automatic reduction in size of the coded network description speeds the computing process by providing the data base that is most efficient for an analysis. There are three network aggregation techniques: subarea windowing, regionwide abstraction, and subarea focusing.

Subarea windowing is the most straightforward technique. There is software that physically extracts a subarea of the network and collapses the external demand for it to within its periphery. This technique can be used for detailed analysis and short-range planning when external demands are assumed to be fixed.

Regionwide abstraction is technically more difficult. The computer reduces detailed networks to a specified

Figure 4. Urban Transportation Planning System functional components.



level of abstraction by aggregating links, nodes, and zonal data, yielding a network amenable to sketch planning. This permits movement from the tactical or short-range stage back to the sketch-planning stage and thus allows rapid macroscopic evaluations of detailed networks.

Subarea focusing is the most difficult technique because it combines windowing and abstraction. A subarea of interest is windowed, but the links outside the window are not deleted but abstracted, so that any modification of the internal network of the subarea can have the appropriate effect on external demand. This is accomplished by increasing the network abstraction as the distance from the window increases. Subarea focusing greatly improves the effectiveness of traditional long-range (tactical) planning by reducing its cost and increasing its accuracy.

Data Acquisition

While data collection is essential to planning in general and system surveillance in particular, the notoriously large sums of money spent for data acquisition should be channeled into more productive analyses. To do this, planners need more efficient data-gathering techniques. UTPS must couple modern sampling techniques with the power of an on-line, time-shared computer and modern data-entry hardware to speed the collecting, editing, and correcting of data and reduce their cost. A disaggregate travel demand data base is available to researchers to eliminate the need for more data in certain cases. Detailed network coding manuals show the planner the quickest way to input the characteristics of his or her transportation system.

Data Management

The data-management system is used to specify network and land use configurations, edit data, and evaluate systems. A good data-management system must allow the planner to execute programs and interact with the data base without detailed knowledge of the design of the data base. It should also be possible to provide a common source of data for all UTPS modules, allow efficient data-base modifications, avoid a proliferation of data files, and furnish a repository for output from computational modules.

Besides the many computational similarities (e.g., matrix manipulation), there are many common data requirements, such as network descriptions, land use data, and graphic data, among the three levels of planning analysis. Therefore, the data preparation time and user-training time are reduced and the software is fully exploited. At any time, the user may modify the basic network or land use data by using the interactive network design program. The modifications can be additions, deletions, or the updating of any or all elements, but the basic integrity of the original design and its predecessors is preserved in a treelike file structure. At any time, the planner may analyze any version of the network. In UTPS a single data base might contain scores of networks, all quickly available for analysis.

The planner can design his network while describing it to the computer in a natural, graphic fashion. He sits at a cathode ray tube and uses a stylus or lightpen to draw the network. He draws it either by explicitly entering nodes, links, transit lines, and such, or alternatively by circumscribing geographical areas of homogeneous service that is described parametrically (e.g., street spacing, number of bus stops, and such).

The UTPS package can generate maps, charts, or graphs. When the software processes a request for graphics, it preserves the results in the graphics file of the data base. The file contains the points, lines, and annotations that constitute the graphic in a standard format. The planner may browse through the available graphics at any time, recalling, combining, modifying, or displaying those needed, without the expense of regeneration. Attribute or land use data can be overlaid on network plots and the graphic directed to a display tube or hardcopy plotter.

CONCLUSIONS

All of the components and capabilities described above are among the current future objectives of the UTPS development effort. All are at present in a research or development stage. A few initial products have already been released to the planning community, but most are scheduled for future delivery.

In its present, skeletal state, UTPS (Figure 4) is 13 software modules and the attendant documentation to form a fairly powerful suite of programs that run in the batch mode on the IBM 360/370 series of computers. It basically comprises a traditional transportation model and best supports long-range tactical planning, but it can provide limited service to the strategic or short-range planner. It includes highway and transit network analysis models, demand-forecasting models, matrix manipulation, and limited graphics capabilities. It can be installed easily at the user's computer facility and is being continually improved.

It is hoped that, within 3 years, UTPS will evolve to include all of the capabilities discussed above. It will be in a form that allows it to be fairly readily installed on non-IBM computers and will exploit minicomputer and nationwide computer network technologies. The result will be a ubiquitously available software system, which will aid our Rip Van Winkle and other federal, state, and local planners who search for effective solutions to today's complex and vexing transportation problems.

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