49-61

TRANSIT SYSTEM PLANNING: A MAN-COMPUTER INTERACTIVE GRAPHIC APPROACH

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A man-computer interactive graphic system for planning node-oriented (multiple-origin to single-destination) transit systems is presented. The system is implemented in a real-time computer environment with a cathode-ray tube. The user designs a transit system by specifying routes, park-and-ride lots, vehicle characteristics, frequencies, fares, and parking fees, and the computer immediately predicts and graphically displays the consequences of this design. The system enables a user to explore and assess a broad range of multiple-attribute alternatives in a short period of time, assists in the search for the best design by automatically generating efficient operating characteristics for given route layouts, makes trade-offs between competing objectives visually apparent, and allows testing of a solution's sensitivity to parametric variations of the model inputs. The paper describes the modal split/network equilibrium model on which the prediction process is based and then illustrates in an example the mechanics and capabilities of the man-computer interactive approach.

•TRANSPORTATION planning, and in particular the planning and design of urban transportation systems, is essentially a problem-solving process. It involves solving the very complex problem of finding the best technology, networks, routes, vehicles, and operating policies under certain physical, economic, and social constraints, where "best" usually refers to many objectives derived from multiple and often contradictory goals (1). This problem-solving process consists typically of cycles, which include five major steps:

1. Objectives are defined;
2. Possible alternative plans are generated;
3. The consequences of each plan are identified by means of some prediction mechanism;
4. These consequences are evaluated in the light of the objectives; and
5. If necessary, the objectives are reformulated.

These cycles are repeated, usually with an increasing degree of detail and specificity, until the "best" plan emerges.

In the past, most of the research efforts have been concentrated on the third step of the cycle, i.e., toward developing sophisticated mathematical models for predicting consequences of a plan, but little effort has been devoted to providing the urban analyst and decision-maker with adequate tools to assist him throughout the entire problem-solving process. Both the input and the output of today's mathematical models do not directly tie into the planning and problem-solving process, but they require digital coding of spatial problems and they necessitate the translation of voluminous computer printouts into reports, graphs, and maps. Moreover, the lengthy waiting for turnaround times interrupts the continuity of the process and often prohibits a great number of iterative cycles.

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Man-computer interactive graphic design is a technique for assisting a human throughout the entire planning process: It enables a planner or analyst to search out and evaluate a large number of alternative designs in a short period of time, it assists in the resolution of conflicting objectives, and it can help a policy-making body to reach compromises after a value-oriented discussion. This paper illustrates this technique by describing the Interactive Graphic Transit Design System (IGTDS), a tool for planning node-oriented park-and-ride transit systems developed at the University of Washington. Previous versions of IGTDS have been discussed earlier (2, 3).

THE INTERACTIVE GRAPHIC TRANSIT DESIGN SYSTEM

Node-Oriented Park-and-Ride Transit Systems

Node-oriented transit systems are defined as public or private transportation systems catering to trip desires that either originate at multiple locations and converge at one central destination (many to one) or originate at one central location and disperse to many locations (one to many). Node-oriented travel patterns are typically found in urban areas with large traffic attractors such as a central business district, a large educational facility, a compact industrial area, or important transportation transfer points such as airports, mass rapid transit stations, or railroad stations. Node-oriented park-and-ride transit systems offer a trip-maker the choice among three major modes: (a) walking to a transit stop and riding to the destination, (b) driving to a park-and-ride lot, parking, and riding transit, and (c) driving directly to the destination. We shall refer to these modes as the walk-and-ride mode, the park-and-ride mode, and the drive mode respectively. The components of a node-oriented park-and-ride system are shown in Figure 1.

Predicting the Consequences of Node-Oriented Transit System Designs

Inherent in IGTDS is a mathematical model that predicts the most likely consequences of a particular node-oriented transit system design, as illustrated in Figure 2. Design variables represent the options open to the designer and/or decision-maker relative to the design of node-oriented transit systems. It is obvious that the number and nature of these options depend largely on the specific setting of the problem: An option that may be open to the decision-maker in one case may be closed in another. (For example, for the design of a transit system oriented to an educational facility, the destination parking fee may be an important design variable, whereas the same variable may be out of the realm of the planner or decision-maker in the case of a CBD-oriented system.) IGTDS contains all those design variables that have important consequences for both the transit system in question and the community served. They are shown on the left side of Figure 2.

Transit system performance should be measured by assessing the quality of service provided in relation to the costs incurred. For transit systems the costs accrue to users in terms of fares or parking fees and possibly to the public at large in the case of a deficit. Quality of service can be measured in terms of accessibility. Also, since trip-makers have the choice between transit and non-transit modes, transit utilization (i.e., modal split and transit system loads) directly reflects the quality of service. The consequences listed on the right side of Figure 2 were felt to be the most important for evaluating a transit system design.

Predicting transit system utilization and system loads involves estimating how many among all the potential trip-makers are likely to use the modes available to them and then assigning the potential system patrons to these modes and system links. Thus, the performance prediction model is essentially a combined modal split and network assignment model.

The modal split model implemented in IGTDS is based on the logistic function (4, 5) of the form

$$W_{im} = \frac{\exp(-I_{im} c)}{\sum_{j} \exp(-I_{ij} c)} \qquad m = 1, 2, 3$$

where W_{im} is the share of mode m among trips from an origin i, I_{im} is the impedance between origin i and the destination via mode m, and c is the constant.

Furthermore, the model is based on the assumption that the average trip-maker travels on the shortest impedance path after a particular mode has been chosen. This can be expressed as

$$I_{im} = \underset{\{P_{im}\}}{\text{Min}} \left(\sum_{j \epsilon P_{im}} d_j \right) + C_m$$

where d_j is the impedance of a link j, C_m is the initial impedance associated with mode m, P_{im} is a path from origin i to the destination via mode m, and $\{P_{im}\}$ is the set of all paths from origin i to the destination via mode m.

The impedance that trip-makers perceive as being associated with a particular trip component (link) is assumed to be a linear function of the amount of time or cost spent during that trip component, i.e.,

$$d_j = c_j \, x_j$$

where c_j is the impedance coefficient associated with the activity over link j, and x_j is the amount of time or cost spent over link j.

Algorithmically, the model adds to the physical network a set of virtual links denoting activities such as waiting or paying fares and fees and then builds shortest impedance path trees through the augmented network (3). An example of impedance paths is shown in Figure 3.

The transit trips generated by the modal split model are assigned on an all-or-nothing basis to the transit lines and parking lots that are incident to the respective shortest impedance paths. Three modes of assignment are provided, as follows:

1. Capacity-constrained assignment—The number and sizes of transit vehicles and parking lot sizes are fixed. If the load on a transit line exceeds the line's seating capacity, the impedance on that line is increased to the level associated with standing and the excess load is subjected to a further modal split/assignment cycle. If in a next step a line's standing capacity is exceeded, the line's frequency is set to zero and the excess load is again recycled. In a similar manner a parking lot is deleted when its load reaches its capacity.
2. Unconstrained Assignment I (Fig. 4, top)—The number of transit vehicles and sizes of parking lots are open. The number of vehicles on each line is calculated to meet the line load. Because the number of vehicles determines the average waiting time (function or frequency) and therefore, in turn, has an impact on modal split, the process must be reiterated. It is interesting to note that, unlike the case of iterative capacity-constrained highway traffic assignment, the level of service on a transit line increases with increasing load. The iteration nevertheless ends because it reaches the point where a marginal increase of volume is smaller than the capacity of one additional transit vehicle.
3. Unconstrained Assignment II (Fig. 4, bottom)—The number of vehicles is fixed, but the sizes of vehicles and parking lots are open. This case does not require an iterative assignment process.

Man-Computer Interactive Graphic Design

By using the prediction model described, IGTDS simulates the operation of a transit system that a user has characterized by selecting a set of options. Two characteristics make IGTDS unique and more powerful than the usual simulation systems available today and particularly suitable for the design and problem-solving process:

1. IGTDS is interactive. An on-line computer environment is provided where the user (i.e., the analyst) controls the computational process and gets an "immediate" response from the system to any input he makes (Fig. 5). This has three desirable consequences. First, he receives the results of a simulation very rapidly and is therefore able to generate and evaluate a large number of alternatives in a very short time.

Second, his thought process is not interrupted by waiting for hours or days for results. This means that less warm-up time is required, there is less forgetting between successive runs, and there will be "a tending toward better performance for highly exploratory and complex tasks"(6). Finally, IGTDS has the capability of greatly reducing the number of unsuccessful runs by editing the analyst's inputs immediately and pointing out errors and unfeasible ideas quickly and directly.

2. IGTDS is graphic. The user communicates with the computer graphically, verbally, and numerically via a cathode-ray tube (CRT) with a keyboard and a graphic input device ("joystick"). Since the user's problem is predominately spatial, graphic communication makes the conversion of graphic data to digital data the task of the machine. This not only eliminates a significant source of human errors but also relieves the analyst of a most tedious task.

SOLVING AN EXAMPLE PROBLEM: DESIGNING A PARK-AND-RIDE BUS TRANSIT SYSTEM FOR CBD-BOUND COMMUTERS OF AN URBAN CORRIDOR

The capabilities and mechanics of IGTDS are demonstrated in the following narration of a typical set of steps that would be followed in the process of planning a transit system in a hypothetical problem environment.

Let us assume that an urban corridor is experiencing severe peak-hour congestion problems, particularly on a multilane limited-access highway that traverses the corridor and links it to the central business district (CBD). Let us further assume that residential density, and thereby density of trip desires, is too low to warrant a high-capacity mass rapid transit link through the corridor. A short-term improvement in this corridor's transportation plight might be a CBD-oriented bus transit system that employs the corridor's freeway for fast linkage of the corridor and the CBD and uses parking lots for park-and-ride service in low-density areas as well as regular feeder bus lines in areas of higher density.

Before the interactive graphic design process can be started, five sets of data must be gathered and loaded into the system:

1. Network data—The street network must be coded in terms of nodes (i.e., intersections) and links. Each link must be annotated with an average automobile speed, walk speed, and transit speed. Again, an interactive graphic process is most suitable for building and editing a network file (7).
2. Demand data—The potential individual trip demands must be aggregated and located at the network node closest to their various actual origins and recorded in a demand file. In most instances these demand data are readily available from institutions located at the destination node in terms of employee or client's files. Such files invariably contain a person's address as the locational descriptor of his trip origin. Geocoding systems such as the U.S. Census Bureau's Admatch-Dime System (8, 9) or Seattle's Geobasys System (10) convert such addresses to coordinates, or even to network node numbers. The trip demands should be stratified into transit captives and non-captives because captives can be assigned to the walk-and-ride mode only.
3. Land value data—The approximate average values of land in the proximity of each node of the network are used for computing the costs of potential parking lots.
4. Transit vehicle data contain the characteristics and per-unit costs of all potential vehicle types that can be used in the design.
5. Calibration data contain the trip-maker behavioral parameters. They describe the relative perceptions of the trip-makers for the different components of a trip by each mode. These data are derived when the prediction model is calibrated. Methods for calibrating a multimode logit model have been discussed by Rassam et al. (5). The user can interactively manipulate the values of the calibration parameters for sensitivity analysis.

Let us now follow a user through the interactive process of designing a node-oriented park-and-ride transit system.

The user controls the interactive process by means of a "menu" from which he can select any of the 30 software modules available to him (Fig. 6). [Figures 6 through 17 are reproduced from slides taken directly from the cathode-ray tube. Although they are not of normal publication quality, the figures serve to illustrate the various steps described.] The modules fall into five classes: (a) data base display, (b) design input, (c) evaluation models, (d) consequence output, and (e) output data management. After the execution of a module, either the user can immediately proceed to the following module, or he can return to the menu and jump to any other module, or he can repeat the same module (if he made a mistake or changed his mind).

The user begins the interactive process by displaying his data base in the form of one or several maps (Fig. 7). The street network, demand pattern, and land-value pattern can be displayed individually or as overlays. The area displayed in our example represents an urban corridor approximately 10 miles long and 5 miles wide.

Next, the user specifies those characteristics at the CBD destination that will affect the impedance of those commuters who do not use the transit system. The inputs are shown in Figure 8.

Proceeding to the next module, the planner is again shown the network and, if he desires, the trip demand and/or land values. Following a query from the computer, the user designates the set of nodes at which he desires to locate parking lots by using the joystick (Fig. 9).

At the next module, the computer asks the user to specify the size of the lots at the locations selected (Fig. 10). Differences in the lot sizes may reflect the user's intuitive perception of the relative trip demand in the vicinity of the lot locations. This step can be skipped if the consequences are to be predicted on the basis of unconstrained assignment.

Next, the parking fees to be levied at the lots must be entered. Fees can be used to manipulate both the overall attractiveness of the park-and-ride mode and the relative attractiveness of individual lots, as well as for determining the revenues of parking-lot operation.

Continuing, the user must lay out the transit routes to serve the parking lots. He is shown the street network, the parking lot locations, and, if desired, the nodal demands. Routes are specified by pointing with the joystick to each node that is to become a transit stop, the computer automatically connecting sequential stops via the shortest path for transit (Fig. 11). The parking lots can be served at any place along a specific route, and more than one transit line can collect passengers at any given stop.

Once the routes are located, the user can select the number and/or types of vehicles that are to serve the various lines. To aid this selection, the routes with the transit stops and parking lots and, optionally, the trip demands are displayed (Fig. 12). In addition, a headway table is presented indicating the potential headways between vehicles for alternative numbers of vehicles operating on a line. The headway of a line has two impacts: It determines the average waiting time of trip-makers at bus stops and hence influences the attractiveness of individual transit lines, and it determines, together with the vehicle type (i.e., size), the capacity of a line, which should be at least in accordance with the capacity of parking lots that are served by a line. In addition, the vehicle type implies the comfort level of a line and hence influences the attractiveness of transit. If unconstrained assignment is to be used, only the numbers of vehicles or the vehicle types on each line must be specified.

The final input required before a configuration can be evaluated is the set of transit fares. Zonal or flat fares schedules may be specified. It is only necessary to indicate the fare at stops where a new fare zone begins—the fares at all other stops are displayed automatically. Again, transit fares have an impact on the attractiveness of transit in general and on the relative attractiveness of individual stops and lots as well as determining transit revenue.

At this point the user selects the mode of the prediction model (constrained or unconstrained). In our example the capacity-constrained mode has been chosen. After a computation time of 2 to 3 minutes the computer is ready to display the consequences of the design as selected by the user.

First, the user may examine the utilization and economics of the transit system as displayed in Figure 13. The "not served" column of the modal split summary indicates

Figure 1. Node-oriented park-and-ride transit system components.

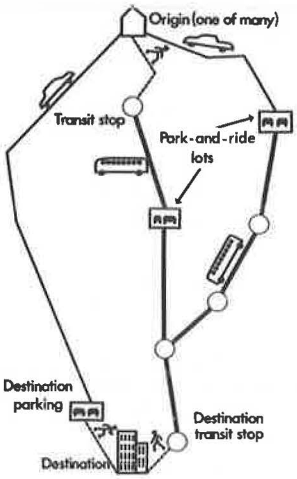


Figure 2. The IGTDS prediction model.

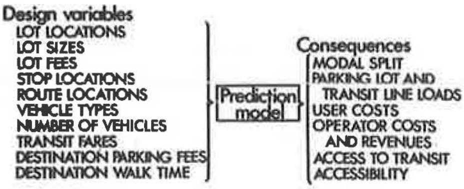


Figure 3. Example of impedance paths via walk-and-ride, park-and-ride, and drive modes.

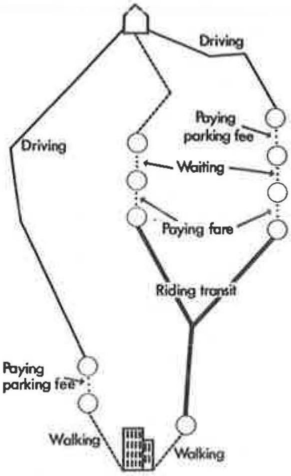


Figure 4. Unconstrained assignment models.

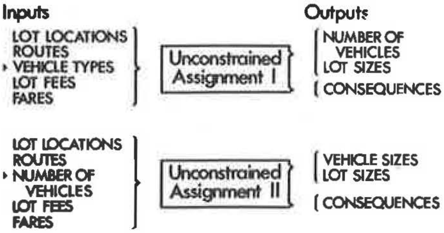


Figure 5. IGTDS computer environment.

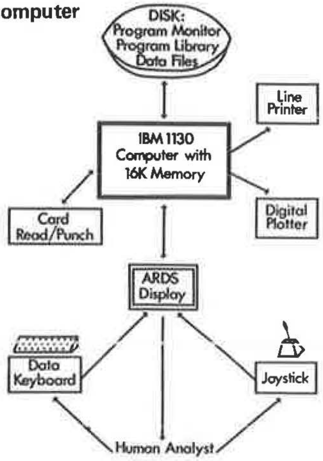
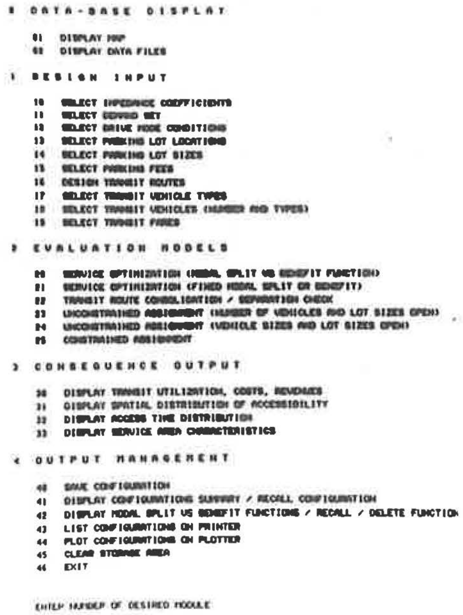
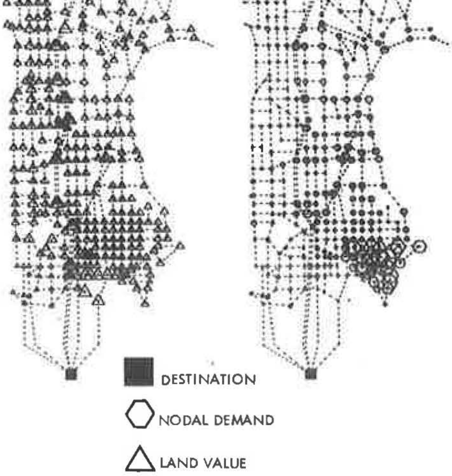


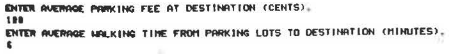
Figure 6. Selection of a module from the "menu".



```
0  DATA-BASE DISPLAY

   01  DISPLAY MAP
   02  DISPLAY DATA FILES

1  DESIGN INPUT

   10  SELECT IMPEDANCE COEFFICIENTS
   11  SELECT DEMAND SET
   12  SELECT DRIVE MODE CONDITIONS
   13  SELECT PARKING LOT LOCATIONS
   14  SELECT PARKING LOT SIZES
   15  SELECT PARKING FEES
   16  DESIGN TRANSIT ROUTES
   17  SELECT TRANSIT VEHICLE TYPES
   18  SELECT TRANSIT VEHICLES (NUMBER AND TYPES)
   19  SELECT TRANSIT FARES

2  EVALUATION MODELS

   20  SERVICE OPTIMIZATION (MODAL SPLIT VS BENEFIT FUNCTION)
   21  SERVICE OPTIMIZATION (FIXED MODAL SPLIT OR BENEFIT)
   22  TRANSIT ROUTE CONSOLIDATION / SEPARATION CHECK
   23  UNCONSTRAINED ASSIGNMENT (NUMBER OF VEHICLES AND LOT SIZES OPEN)
   24  UNCONSTRAINED ASSIGNMENT (VEHICLE SIZES AND LOT SIZES OPEN)
   25  CONSTRAINED ASSIGNMENT

3  CONSEQUENCE OUTPUT

   30  DISPLAY TRANSIT UTILIZATION, COSTS, REVENUES
   31  DISPLAY SPATIAL DISTRIBUTION OF ACCESSIBILITY
   32  DISPLAY ACCESS TIME DISTRIBUTION
   33  DISPLAY SERVICE AREA CHARACTERISTICS

4  OUTPUT MANAGEMENT

   40  SAVE CONFIGURATION
   41  DISPLAY CONFIGURATIONS SUMMARY / RECALL CONFIGURATION
   42  DISPLAY MODAL SPLIT VS BENEFIT FUNCTIONS / RECALL / DELETE FUNCTION
   43  LIST CONFIGURATIONS ON PRINTER
   44  PLOT CONFIGURATIONS ON PLOTTER
   45  CLEAR STORAGE AREA
   46  EXIT

   ENTER NUMBER OF DESIRED MODULE
```

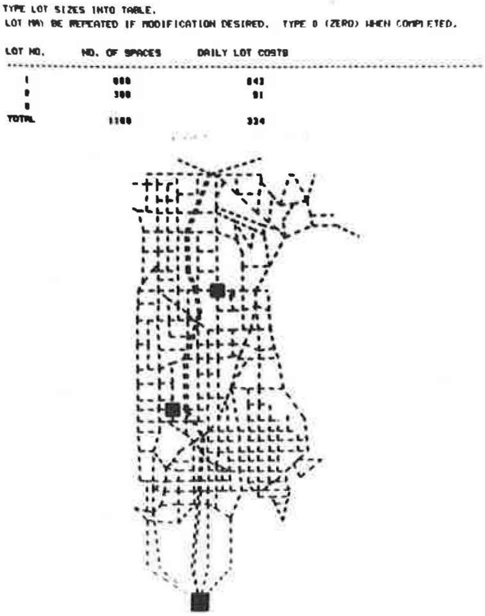
Figure 7. Street network, demand pattern, and land-value pattern.





```
ENTER AVERAGE PARKING FEE AT DESTINATION (CENTS).
100
ENTER AVERAGE WALKING TIME FROM PARKING LOTS TO DESTINATION (MINUTES).
6
```

Figure 8. Selection of drive-mode constraints.

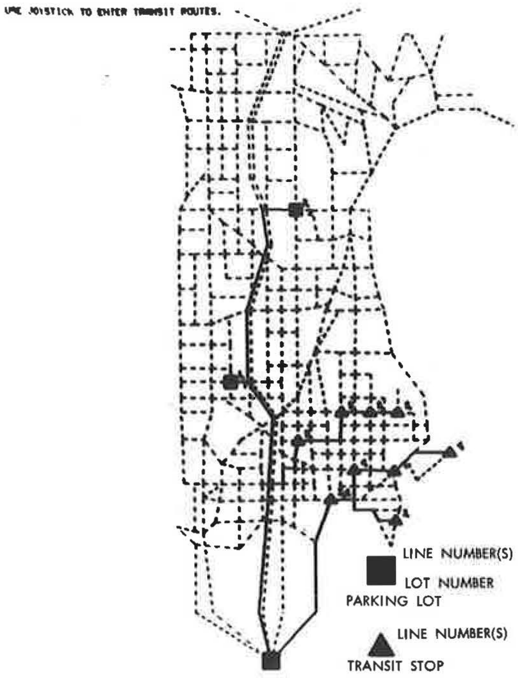


```
TYPE LOT SIZES INTO TABLE.
LOT MAY BE REPEATED IF MODIFICATION DESIRED.  TYPE 0 (ZERO) WHEN COMPLETED.

LOT NO.       NO. OF SPACES       DAILY LOT COSTS
*****************************************************************************
   1               800                 243
   2               300                  91
   0
TOTAL             1100                 334
```

Figure 10. Selection of parking lot sizes.

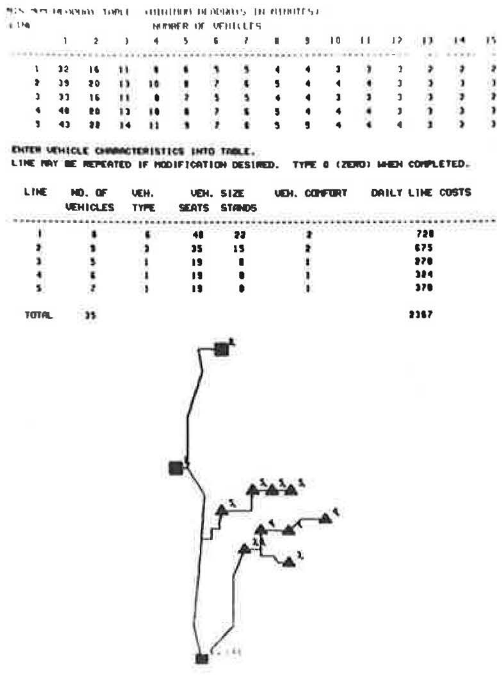
```
USE JOYSTICK TO LOCATE PARKING LOTS.
```

Figure 9. Selection of parking lot locations.



```
USE JOYSTICK TO ENTER TRANSIT ROUTES.
```

Figure 11. Selection of transit routes.



```
BUS MIN HEADWAY TABLE   (MINIMUM HEADWAYS IN MINUTES)
LINE                          NUMBER OF VEHICLES
         1     2     3     4     5     6     7     8     9    10    11    12    13    14    15
*********************************************************************************************
   1    32    16    11     8     6     5     5     4     4     3     3     3     2     2     2
   2    39    20    13    10     8     7     6     5     4     4     4     3     3     3     3
   3    33    16    11     8     7     5     5     4     4     3     3     3     3     2     2
   4    40    20    13    10     8     7     6     5     4     4     4     3     3     3     3
   5    43    22    14    11     9     7     6     5     5     4     4     4     3     3     3

ENTER VEHICLE CHARACTERISTICS INTO TABLE.
LINE MAY BE REPEATED IF MODIFICATION DESIRED.  TYPE 0 (ZERO) WHEN COMPLETED.

 LINE    NO. OF    VEH.     VEH. SIZE     VEH. COMFORT    DAILY LINE COSTS
        VEHICLES   TYPE   SEATS  STANDS
*****************************************************************************
   1        8        6      40     22          2                720
   2        9        3      35     15          2                675
   3        5        1      19      8          1                270
   4        6        1      19      8          1                324
   5        7        1      19      8          1                378

 TOTAL     35                                                  2367
```

Figure 12. Selection of transit vehicles.

the percentage of trip-makers who are transit captives and do not receive adequate transit service. The detailed cost-revenue figures for transit lines and parking lots may be studied for subsequent elimination, relocation, or repricing of unprofitable lines and lots. In addition, lot loads and lot sizes may be compared for further adjustment of parking lot sizes. The annotated access volumes at each stop and lot may help subsequent elimination of "unpopular" stops. Care has to be taken, however, because low-access volumes may also stem from missing capacity of in-bound transit vehicles when they reach a stop.

The next two displays given by the computer (Fig. 14) show the spatial distributions of accessibility. They can be used to identify those areas where an improvement in service is most needed.

The distribution of service provided by the transit system may also be assessed in terms of the percentages of the trip-making population within certain ranges of access time to transit stops or parking lots (Fig. 15). For example, these displays might be used to check whether a sufficiently large portion of transit captives is within tolerable walking time from transit stops. The standard deviations of the access time distributions can be interpreted as a measure of the spatial equity of the system.

The final displays given by the computer show the service area characteristics for the walk-and-ride mode or, as in Figure 16, for the park-and-ride mode. In Figure 16, the service areas of the parking lots are defined by "trees" that show the paths on which people would drive to parking lots if they chose the park-and-ride mode. A locationally efficient solution may be characterized by the absence of backtracking paths and by service areas that are well balanced in size (see "demand" column of table) and average and maximum access times.

At any point during evaluation of the performance displays, the user can save his current configuration on the computer's disk, go back to any of the decision input modules, and re-enter modified design variables. He can also display a comparative summary of all the configurations that he has generated and saved, delete any of the saved configurations, recall a previously saved configuration for the purpose of subsequent modification, and obtain printed or digital plotter hard copies of any or all configurations.

ADDITIONAL SEARCH CAPABILITIES OF IGTDS

Initially, it was hoped that the interactive design process described would enable a user to find rapidly a large number of efficient solutions. (A solution is termed "efficient" if it cannot be dominated, i.e., if no improvements in total benefit can be made without a simultaneous decrease in total transit use.) Initial experience with IGTDS revealed, however, that unless the problem was stringently constrained the user was overwhelmed by the number of design variables and the astronomical number of possibilities they offer. Most users felt reasonably confident in making locational decisions (locating parking lots and designing routes), but they felt uneasy in the decisions as to level of service and pricing. It was, therefore, felt desirable to automate the search for efficient combinations of frequencies, fares, and parking fees.

The automated search process implemented in IGTDS contains two steps. In the first step the computer generates the trade-off function between transit use and operator benefit for a given route layout (Fig. 17). The process uses a partially inverted form of the modal split and unconstrained assignment model. In the second step the user specifies a point on the trade-off curve and thereby the combination of fares, number of vehicles, and lot sizes associated with that point. The user can immediately proceed to displaying the consequences, because they were already calculated when the curve was generated. The net computation time for the entire search process is approximately 3 minutes.

Choice of the "Best" Among Multiple-Attribute Alternatives

The combination of intuition and computer-assisted search should allow a user to find in a relatively short time a number of solutions that are acceptable with respect to his design criteria. However, having identified a number of acceptable solutions,

```
                     M O D A L   S P L I T   S U M M A R Y
         PERCENTS   WALK+RIDE      PARK+RIDE        DRIVE       NOT SERVED
         ---------------------------------------------------------------
                      14.6           12.0           71.0            .2

                       T R A N S I T   L I N E   S U M M A R Y
LINE   NO VEH  SEATS/VEH  STAND/VEH  COMFORT  HEADWAY   COST  REVENUE  BENEFIT
-------------------------------------------------------------------------------
  1       8       40         20         2       3.0      720     836       116
  2       9       35         15         2       4.3      675     520      -155
  3       5       10          0         1       6.9      270      68      -202
  4       6       10          0         1       6.5      324     145      -179
  5       7       10          0         1       6.1      378     124      -254
TOTAL    35                                             2367    1693      -674

                     P A R K I N G   L O T    S U M M A R Y
 LOT NO    LOT SIZE  LOT LOAD  LOT FEE  LOT FARE          COST  REVENUE  BENEFIT
-------------------------------------------------------------------------------
    1         800       732       0        50              243      0      -243
    2         300       225       0        50               91      0       -91
TOTAL        1100       957                                334      0      -334

TOTAL SYSTEM                                              2701    1693     -1008
```

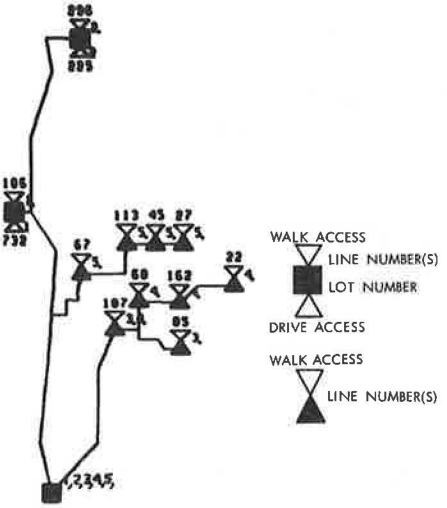


Figure 13. Presentation of modal split and cost/revenue figures.

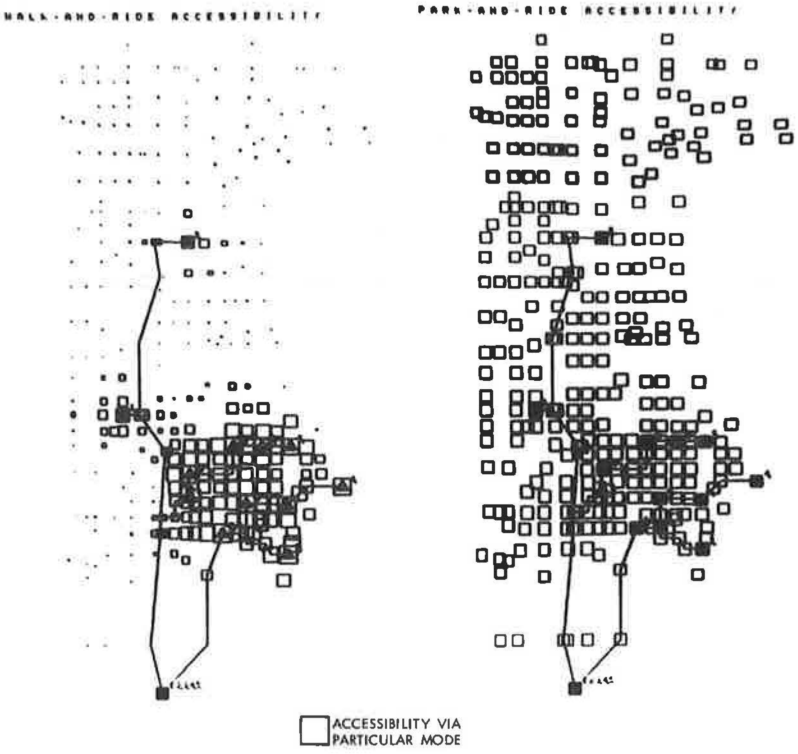


Figure 14. Spatial accessibility distribution.

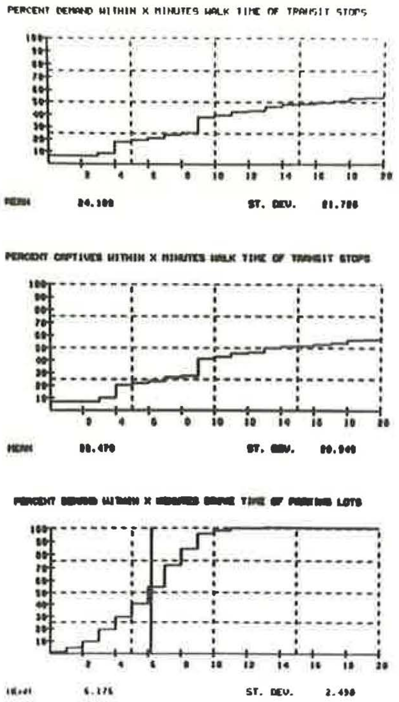


Figure 15. Distribution of access to the transit system.

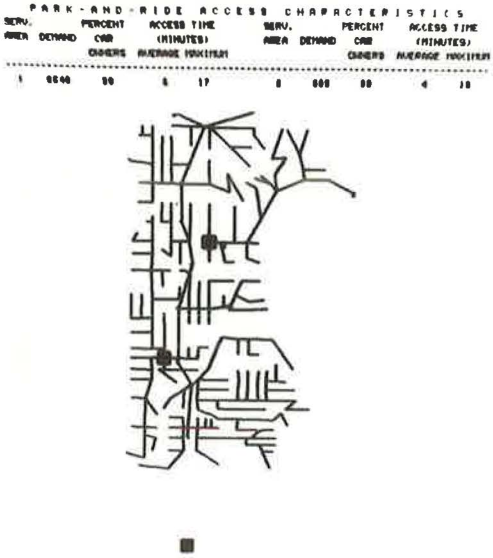
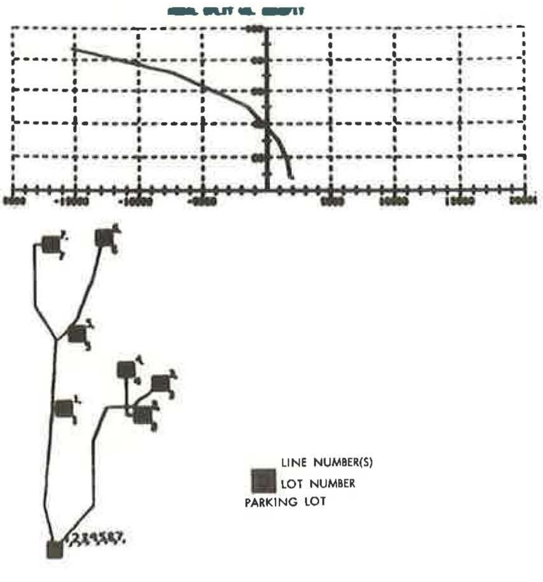


Figure 16. Service area characteristics for park-and-ride mode.

Figure 17. Configuration and associated trade-off function.

THE FOLLOWING LOT LOCATIONS ARE INEFFICIENT



the user will still face the difficult task of selecting the "best" solution from them. Each acceptable alternative will achieve different levels of satisfying competing objectives such as maximum transit ridership, maximum operator benefit, minimum user costs, and minimum variation of accessibility. However, IGTDS makes apparent the extent to which certain pairs of goals are incompatible. The automated search process displays the trade-off function between transit use and operator benefit explicitly. In selecting a point of the curve of Figure 17, the user can apply a criterion of (a) a given profit or deficit level, (b) a given minimum transit use requirement, or (c) an objective function of the two performance measures. Additional trade-offs will become apparent when the values of other performance measures are compared in the summary tables. The knowledge of trade-offs allows the user-participants to identify compromises and to generate new alternatives in a framework of reformulated objectives and constraints.

Additional Choice Models

The interactive graphic approach is particularly well suited for computer-assisted decision-making among multiple-attribute alternatives. IGTDS does not yet contain specific choice models, but such models could be incorporated in the future. Computer assistance seems desirable for such decision-making methods as dominance, satisficing, maximin or maximax, lexicography, additive weighting, effectiveness index, nonmetric scaling, and others (11). Of particular interest are semantic scaling techniques for multiparticipant decision-making. Flack and Summers (12) have developed a promising prototype interactive graphic system for highlighting and resolving the differences in the value systems of two participants choosing among water resource system alternatives.

LIMITATIONS

IGTDS is currently limited to problems involving a network of up to 320 nodes and 1,280 one-way links. This limitation stems from the IBM 1130 memory capacity (16,000, 16-bit words) and disk size (½ million words). Also, larger problems would entail partitioning the network for display purposes (the ARDS display area is 6 x 8 inches). Implementation of IGTDS on a large third-generation computer would reduce net computation time by a factor of between five and ten.

Limited to many-to-one trip relationships, IGTDS cannot be directly applied to multidestination transit systems. However, urban transit systems can often be decomposed into node-oriented subsystems serving particular destinations and homogeneous clienteles and trip purposes. IGTDS can be used for designing such subsystems, although their superposition may require manual adjustments such as consolidating redundant routes and resolving inconsistent fares.

CONCLUSIONS

Decision-oriented transportation planning requires

> . . . more sophisticated tools of analysis to perceive individual and community preferences and formulate goals and program objectives in light of evolving technology and changing habits and values; to search for and generate alternative approaches to meet given objectives; to predict, evaluate and then rank the impacts of alternative proposals; and to give adequate recognition to the element of uncertainty in the design of decisions (13).

The man-computer interactive graphic design system presented in this paper comes very close to meeting the requirements quoted:

1. It enables the user to explore a wide range of alternatives, including "unusual" designs, and it helps him to find efficient solutions.
2. It allows a user to answer "what if" questions quickly. (It is foreseeable that interactive graphic systems with a wall-size display could be used to answer questions in public hearings, thereby enhancing a truly participatory planning process).

3. It does not require the formulation of a quantitative objective function at the outset of the design process but gives recognition to the fact that the true value systems of decision-makers emerge only when they are faced with hard trade-offs.

4. It allows the user to test the sensitivity of a solution with respect to certain model inputs such as travel demands and modal split model parameters.

5. Because it provides deep insight into the many interactions inherent in any transportation system, it is also a suitable educational and research tool.

To date, work on IGTDS has only been developmental. Future work will include controlled experimental use of IGTDS and, it is hoped, will lead to a proper assessment of the system's potentials for real-world problem-solving and research and educational use. Work is under way to calibrate the IGTDS prediction model and to apply it to a real-world problem. In addition, controlled experimental use of the system is expected to yield some evidence on the suitability of interactive graphic systems for solving transportation problems of various levels of complexity. Of particular interest is the identification of successful problem-solving strategies that can be implemented with computer heuristics and ultimately be used for creating an interactive system in which the computer learns from the user.

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