Computer Graphics for Transit Planning: An Empirical Study

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This paper documents the results of a case study in which an interactive graphics system was applied to solve a bus transit design problem. The aim of the study was to gain insights into the applied use of the interactive graphics system and to assess its utility as a practical sketch-planning tool. The particular system used was the Interactive Graphic Transit Design System (IGTDS), and the problem to be addressed was the design of a bus system in the Southfield-Jeffries Corridor in southeast Michigan. The study consisted essentially of a data-base development phase and a system-application phase. The results of the case study are reported in terms of (a) the user requirements for data-base development, (b) the general on-line problem-solving experience by using IGTDS, (c) the efficiency characteristics of the IGTDS design process, and (d) the on-line times and costs associated with IGTDS operation. The major findings were that IGTDS was simple to use, that the application costs were relatively low in terms of both data-base development and system operation, and that the IGTDS design process was quite efficient in generating design solutions to the relatively complex bus transit problem (i.e., 81 designs in 24 h of on-line time). These findings suggest the strong potential of interactive graphics systems like IGTDS as practical and cost-effective sketch-planning tools.

The application of interactive computer graphics in designing public transportation services is a relatively new and important research effort. The potential benefits of interactive graphics methods include fast response to planning and design questions (and thus the capability for exploring in a timely manner a wide range of alternative solutions to a particular design problem) and the capability for assimilating graphic as well as alphanumeric information. Since transportation problems in general--and transit design problems in particular--are spatially oriented, the graphic capability can ease the user burden in problem definition and analysis and can help eliminate errors prevalent in coding spatial information (e.g., network coding errors).

Despite these apparent advantages, application of interactive graphics to transit system planning and design has been limited. Several prototypical interactive graphics systems have been developed to aid in the transit system design process (1-5), but for the most part little has been reported regarding the potential of these systems as practical design tools.

This paper documents a case-study application in which an interactive graphics system was used by a group of designers to solve a bus transit design problem by using actual transit system data. The system used was the Interactive Graphic Transit Design System (IGTDS) (5). Developed principally at the University of Washington by Rapp (6), IGTDS is currently distributed to the public by the Urban Mass Transportation Administration (UMTA) of the U.S. Department of Transportation. The case study consisted of two major phases: a data-base development phase and a system-application phase. The data-base development phase of the study was carried out at the General Motors (GM) Technical Center in Warren, Michigan, by the GM Transportation Systems Division (GMTSD). The site selected for the case study was the Southfield-Jeffries Corridor in southeast Michigan. The system-application phase was carried out at Northwestern University by a group of transportation engineering graduate students who were asked to use IGTDS to assist in designing a bus system that would serve trips that originated in the Southfield-Jeffries Corridor and were destined for the Detroit Medical Center.

The primary objectives for conducting the case study were as follows:

1. To ascertain and document the user requirements involved in IGTDS data-base development,
2. To observe the general problem-solving experience that characterized the IGTDS design process and to document the various design strategies employed and the quality of the resulting design solutions,
3. To determine the design efficiency characteristics of the IGTDS design process, and
4. To determine the user costs involved in IGTDS operation.

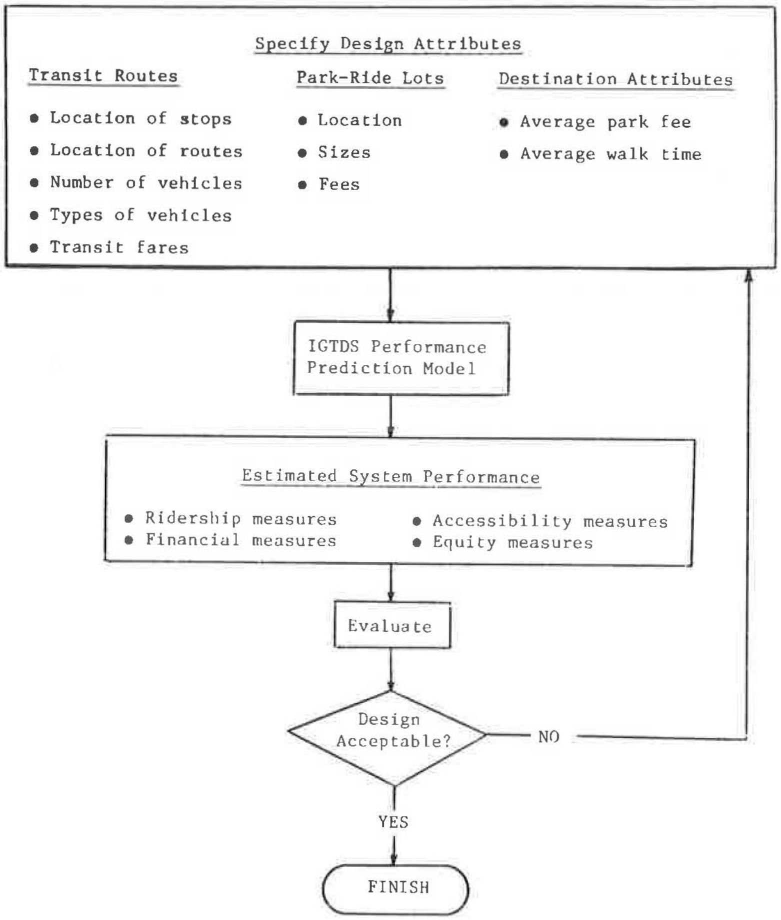
THE SYSTEM (IGTDS)

IGTDS is a tool for assisting in the design and evaluation of alternative transit systems that serve many trip origins and a single major destination (i.e., many-to-one services). IGTDS is designed to be used principally as a sketch-planning aid by which design changes (i.e., changes in transit level of service) can be executed rapidly and corresponding measures of transit performance can be made available almost instantantly to the planner and designer for evaluation. At the heart of IGTDS are a mode-choice model called the n-dimensional logit model (7) and a capacity-restrained transit assignment model. For any given design specification, this model estimates the number of trip makers likely to use each of the modes available in IGTDS (i.e., drive, park-and-ride, and walk-and-ride) and assigns these trips to the transportation network via the shortest impedance paths.

IGTDS allows the user to manipulate the various design variables easily and thus to change the relative trip impedances and predicted shares for the given modes. Any element--from a complete redesign of the transit route structure to a modification of the fare at a single stop--can be handled at the computer graphics terminal, through either graphic input (i.e., via the terminal display screen cursor) or alphanumeric input (i.e., via the terminal keyboard). Based on the estimated modal shares and subsequent assignment of transit system loadings for a given design, a set of performance measures is computed and can be displayed graphically. These performance measures are used to evaluate the given transit system design. The general transit system design process that uses IGTDS is illustrated in Figure 1. This iterative process consists essentially of three steps: (a) specifying design attributes through interactive input by using IGTDS, (b) obtaining system performance estimates from IGTDS, and (c) evaluating the design and modifying it if it is unacceptable. This is the basic design process used by the student designers in the case-study application.

The basic hardware requirements for operating IGTDS software are either a PDP-10 or an IBM series 370 computer and a Tektronix series 4010 graphics terminal.

Figure 1. Transit design process that uses IGTDS.



DATA-BASE DEVELOPMENT

The data base required for operating IGTDS consists primarily of information that describes the geography of the study region, which includes the regional demand for travel to the specified activity area (i.e., the destination) and the underlying transportation network (e.g., the highway system) that serves trips within the region. The transportation network serves as a geographic base map for the IGTDS design process, since all regional attributes (including trip origins and some transit system attributes) are assigned directly to elements (i.e., links and nodes) of this network. Associated with each network node are Cartesian (i.e., X,Y) coordinates (for facilitating spatial displays of the network) and the average land value and trip-making demand associated with the subarea represented by the given node. Associated with each link are the travel times that correspond to each of the competing travel modes (i.e., walk, automobile, and transit). When this network information and some additional transit-vehicle-specific data (i.e., vehicle types, capacities, and operating costs) are available, a transit system may be designed (essentially by overlaying the design on the base network), the mode-choice--network-assignment procedure can be executed for the given design, and the various performance measures can be computed and displayed.

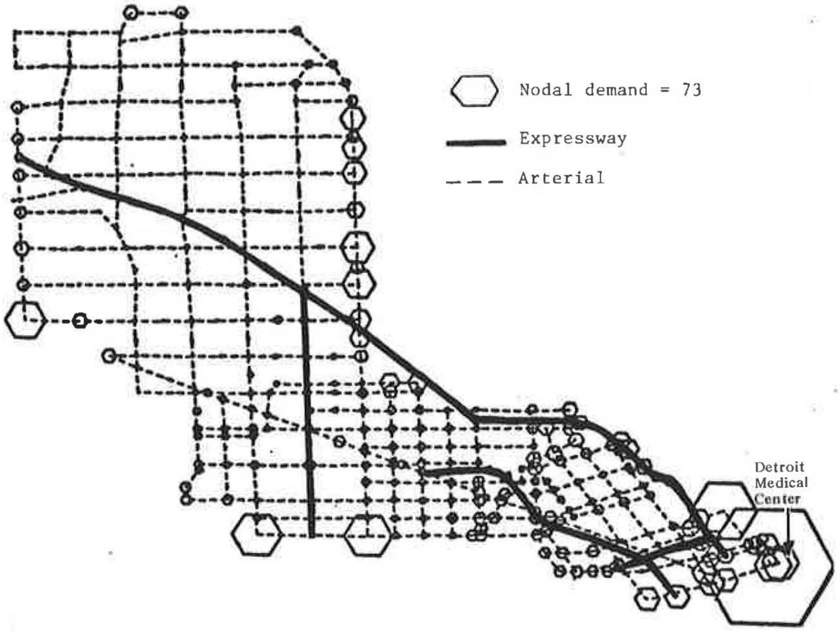
The primary tasks involved in developing the IGTDS data base for this case study were found to be (a) the creation of a link-node network at a suitable level of detail for the application, (b) the assignment of transit and automobile link travel times, and (c) the assignment of trip origins to the network nodes. The methods used to carry out these tasks are described in detail in a GMTSD report (8).

The entire IGTDS data-base development phase for this study required approximately three person weeks of a graduate student's effort. This requirement can be expected to vary in other cases depending on the problem size and the availability of data and data-processing capabilities. However, it appears that in most planning environments the level of effort required for this task would not exceed one person month.

SYSTEM APPLICATION

Following the data-base development phase, IGTDS was applied by a group of Northwestern University graduate students to aid in solving a bus system design problem. Six design teams of two to three students each were formed, and each was asked to design a bus system to serve peak-period trips that orginated in the Southfield-Jeffries Corridor and terminated at the Detroit Medical Center. An explicit procedure was specified for evaluating the bus system design solutions, and each team attempted to develop the best possible solution under this scheme. The teams were each given two 2-h on-line sessions in which to use IGTDS to develop their designs. Prior to the on-line design sessions, the entire group met for a 2-h instruction session and a 2-h on-line demonstration of IGTDS. Each team worked independently on the problem, and competition among teams was encouraged. None of the participants had had any prior experience in using IGTDS.

Figure 2. IGTDS representation of network and demand data for Southfield-Jeffries Corridor.



The formal definition of the design problem (as specified to the design teams) consisted essentially of the following three elements:

1. Network and demand characteristics,
2. Trip-maker behavioral assumptions, and
3. Design evaluation procedure.

Network and Demand Characteristics

The network and demand characteristics of the study area were basic elements in defining the spatial structure of the problem. The area of the Southfield-Jeffries Corridor (Figure 2) is approximately 347 km^2 (125 $miles^2$). The total peak-period demand for trips to the medical center for this problem was 4158. As indicated in Figure 2, the demand at each node is represented by a hexagon whose size is proportional to the magnitude of the demand.

Trip-Maker Behavioral Assumptions

The IGTDS mode-choice--network-assignment model divides all travel to the destination point among the three modes available (i.e., drive, walk-and-ride, and park-and-ride). The share of trip makers who choose a particular mode is based on the relative disutility to travel by that mode. The disutility for a given mode is described by a linear disutility equation that has behavioral coefficients assigned to each component of a trip by that mode. The disutility equations for each mode for the case-study design problem were known explicitly by each of the student designers.

Design Evaluation Procedure

In order to guide the development of the bus system designs, a specific evaluation procedure was devised. The procedure was quite simple and facilitated rapid evaluation of alternatives during the on-line design sessions. The form of the evaluation scheme is discussed below.

The principal objective for designing the bus system was that of maximizing the number of transit patrons. The performance standards represented minimum and maximum values of the performance measures for other important transit objectives (i.e., those that pertained to net operating loss, accessibility and equity of service, and user costs) to ensure that these objectives were fulfilled to an acceptable degree. The design constraints consisted of hardware and software limitations (i.e., maximum number of bus stops, bus lines, and park-and-ride lots allowed by the model) and environmental restrictions (i.e., bus fleet size characteristics, average destination parking fee and walk-access time, and daily park-and-ride lot operating cost). The overall quality score for a given bus system design was thus equivalent to the total number of transit patrons who used the system; however, a score of zero was given if the acceptable standards were not satisfied.

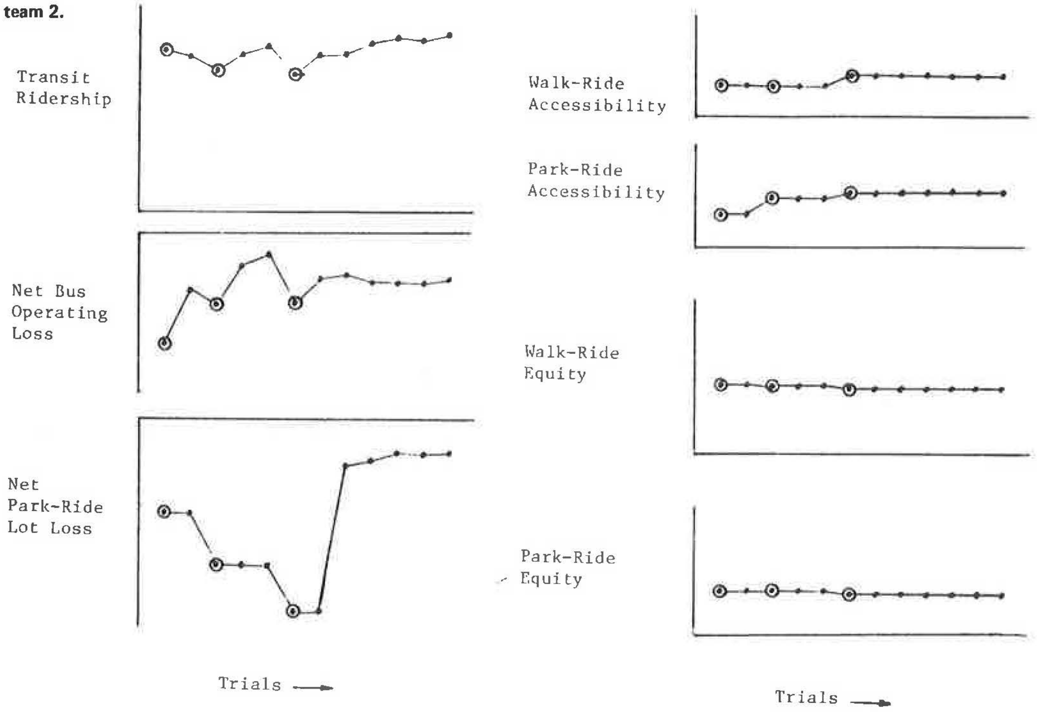
RESULTS

The results of the case-study application are presented below in terms of the project objectives outlined in the introduction to this paper.

General Problem-Solving Experience by Using IGTDS

The behavior of the individual teams during the on-line design sessions was quite diverse and interteam comparisons are difficult. Generally, the teams spent the first of their two on-line sessions in an exploratory manner, becoming familiar with the operation of IGTDS and gaining insights into the relationships among the design variables and performance measures. No team showed evidence of a well-defined plan of attack, although most teams had thought out their first-cut designs to some extent prior to their on-line time. All first-cut designs exhibited poor performance in terms of accessibility to users, since most teams either had underestimated the required density of bus stops or had failed to locate the stops strategically (i.e., near large demand clusters). Subsequent trial configurations improved the accessibility attributes so that they eventually surpassed the acceptable standards. Each team tried from one to three different route configurations and tested from two to six sets of operating and pricing policies (i.e., lot sizes and

Figure 3. Performance profiles for team 2.



fees, bus frequencies, and bus fares) on these configurations during their first sessions. No design team achieved a feasible solution (i.e., a solution that met the acceptable standards) during their first session.

The design teams appeared to be more systematic in their second on-line sessions than they had in their first. Each team had had a chance to study the hard-copy prints of their design decisions and concomitant performance characteristics from the first session. Each team was now familiar with the use and capabilities of IGTDS. Hence, the teams entered the second session with clearer strategies for laying out their routes and for making subsequent modifications to their designs. For example, the two teams that eventually developed the highest-performing designs each formulated a strategy of implementing short high-capacity express park-and-ride routes to the destination. These two teams subsequently concentrated their efforts on modifying the operating and pricing policies for those routes.

In order to monitor its progress during each on-line session, each team plotted the values of the performance measures for successive trial designs. Typical performance plots, or profiles, are illustrated in Figure 3 for team 2. As can be seen, significant shifts in performance generally occurred when a new route configuration was attempted; this is indicated by the circled points on the profiles in Figure 3. As for the accessibility and equity measures, variations occurred only when there were new route layouts (as expected) and these were generally small unless radical route changes were implemented. For ridership and net system losses, variations in performance occurred for nearly any type of modification; this included changes in the system operating and pricing policies.

For every team, the best design was obtained on the last trial. The teams were each able to produce from 7 to 11 feasible designs, and in all cases these constituted more than half the total number of trial designs by each team. A total of 81 trial designs was developed by all teams combined; 50 of these were considered feasible.

The characteristics of the final or best designs of each team were quite diverse, but similarities did appear to exist along some dimensions. Visually, all the designs were complex. Figure 4 provides a graphic example of one of the final designs. Each of the designs consisted of some routes along the southern and eastern perimeters of the corridor, and all exhibited a greater density of stops and routes near the medical center (where the distribution of demand was denser). The physical attributes, or design-parameter quantities, of the final designs are listed in Table 1. As can be observed, there was no variability in the number of buses employed in each design, since the constraint on bus-fleet size was binding in all cases. The only other constraint that was binding was the one placed on the number of bus stops, but this was not a limitation in all cases (e.g., the design produced by team 2 employed only 39 stops, or 10 fewer than were allowed). In terms of the remaining three physical attributes, there was a greater degree of variability among the six designs. The differences in these attribute values were significant and gave an indication of the wide range of solution paths taken by each team.

In terms of the performance attributes of the final designs, the values for total estimated transit patronage ranged from 1432 (i.e., transit mode split = 34.4 percent) to 2010 (i.e., transit mode split = 48.3 percent). Below is a list of the estimates of transit patronage by each design team.

	Total Transit Patronage			
Team	No.	Percentage of Total	Walk-and-Ride (%)	Park-and Ride (%)
1	1432	34.4	10.3	24.1
2	1733	41.6	15.8	25.8
3	2010	48.3	10.5	37.8
4	2007	48.3	14.1	34.2
5	1491	35.8	18.8	17.0
6	1483	35.6	17.1	18.5

Figure 4. Route display of a final design.

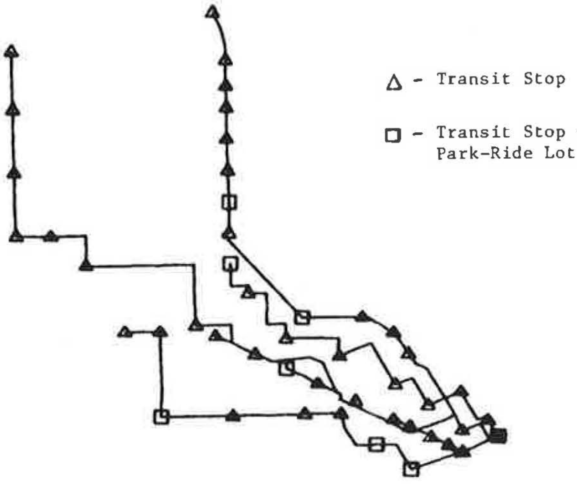


Table 1. Physical attributes of final designs.

Team	No. of Stops (constraint ⩽ 49)	No. of Lines (constraint ⩽ 20)	No. of Buses (constraint ⩽ 40)	No. of Lots (constraint ⩽ 20)	No. of Stalls (no constraint)
1	47	6	40	7	1084
2	39	7	40	8	1200
3	46	5	40	12	1718
4	46	6	40	7	1470
5	46	7	40	10	950
6	49	9	40	9	940

In all but one case, the estimated share of the park-and-ride mode was greater than that for the walk-and-ride mode, and the share of park-and-ride users was generally greater for the designs that attracted greater total transit ridership. The reason for this was that the higher-performing designs (i.e., those developed by teams 2, 3, and 4) took advantage of the utility of a short large-capacity express park-and-ride route near the destination. The other designs did not exploit this resource; rather, park-and-ride demand was distributed in these designs to several smaller-sized lots located in areas farther out from the destination, at which the disutility for the park-and-ride mode was greater (since bus rides were longer). Hence, lower patronage estimates were achieved in these latter designs. In general, it was difficult to draw strong inferences as to the relationships between the design variables and performance results, since so many interaction effects were taking place and so many possible combinations of route structures, operating policies, and pricing policies (including zone fares) were attempted.

Design Efficiency Characteristics

Two basic questions posed prior to conducting the case-study application were how efficient the design process was by using IGTDS or, more specifically, whether use of IGTDS encouraged systematic development of improved transit designs. To address these questions, the performance profiles (see Figure 3) for each team were analyzed. From examining the curves of the ridership profiles, it was found that the ridership scores increased monotonically for each team once the initial feasible designs had been achieved (i.e., the first designs that satisfied all the performance standards and design constraints). To measure the amount of improvement in design quality experienced by each team, the ridership levels of the final designs were compared with those of the corresponding initial feasible designs.

In terms of percentage of improvement from the initial ridership levels, the teams averaged an improvement of 26 percent from their initial feasible scores. Team 1 appeared far superior to the other teams; they had an improvement score of 60 percent. It would not be strictly correct to assert that team 1 was more efficient than the other teams in improving its design, however, since the values of the initial scores of each team significantly influenced their efficiency scores. For example, team 1, although it had the highest improvement score, had the lowest initial quality score. Thus, team 1 had theoretically a greater capacity for improvement than did the other teams. In general, the teams that had smaller initial quality scores tended to improve their designs by a greater percentage than did the teams that had larger initial quality scores.

On-Line Time and Cost Characteristics

Detailed information on user and computer time costs was recorded during all on-line sessions. The time costs to users for each on-line design session were broken down into three components--interaction time, thought time, and error time. The interaction time, or input and output time, was the time during which the teams were either transmitting information to the computer via the terminal keyboard (input) or receiving information via the cathode-ray tube screen (output). The thought time was the time during which the teams were contemplating their design decisions and were not interacting with the computer. The error time represented the time lost due to user input errors, such as mistyping a key or issuing commands in an improper sequence. The component on-line times are listed in Table 2.

As can be seen, the amount of thought time exceeded the amount of interaction time in nearly all cases. The portion of on-line time devoted to interaction with IGTDS ranged from 27 percent to 49 percent and averaged 38 percent. The portion of on-line time devoted to thought about the problem ranged from 48 percent to 69 percent and averaged 56 percent. The time lost due to error was relatively minimal; it consumed a maximum of 13 percent and an average of 7 percent of the total on-line time. The central-procesing-unit (cpu) time used by each team varied between 2.29 and 5.64 min; the total was 20.55 min. The cpu time required to develop each trial design ranged from 0.174 min to 0.343 min, which averaged 0.255 min per design. The differences in cpu times for each trial were due primarily to differences in the number of interactions (i.e., executions of IGTDS program modules) required to develop each design. The average number of interactions per design was four. These cpu times that characterize the IGTDS design experience were much lower than had been anticipated given the size and complexity of the design problem.

CONCLUSIONS

The data-base development requirements for applying IGTDS in this case study appeared to be relatively moderate (i.e., three person weeks of graduate-student effort), especially considering the size and complexity of the design problem addressed. These requirements also seem reasonable when the unlimited number of alternative design

Table 2. Component on-line times.

	Interaction Time		Thought Time		Error Time	
Team	Minutes	Percentage of Total	Minutes	Percentage of Total	Minutes	Percentage of Total
1	81	33.8	154	64.2	5	2.0
2	90	37.5	127	52.9	23	9.6
3	117	48.8	114	47.5	9	3.7
4	91	37.9	118	49.2	31	12.9
5	97	40.4	124	51.7	19	7.9
6	65	27.1	165	68.8	10	4.1
Mean	90	37.5	134	55.8	16	6.7

Note: Total time for each team was 240 min.

solutions that could have been produced by using the original data base is considered. It is hypothesized that, as use of interactive systems like IGTDS becomes more prevalent, even greater economies can be achieved if a central data base is developed initially for an entire region rather than for just a corridor or subarea. Such a strategy would obviate the need for creating a new data base from scratch each time a corridor study was initiated; rather, the required corridor data base could essentially be extracted from the existing regionwide data base. As tools become increasingly available for automating the acquisition and management of transportation data (e.g., graphic tablets and network editor systems) the data-base development task will decrease even further in significance.

In regard to the application of IGTDS in the transit design process, several important findings were produced. In the identification of a useful problem-solving technique to be applied in conjunction with IGTDS, the results of the design experience provided a number of insights. A reasonably effective design strategy appeared to be one characterized by the following elements:

1. Thorough knowledge of the problem definition,
2. Preparation of initial designs on paper prior to on-line sessions,
3. Review of the results from preceding design sessions prior to each on-line session,
4. Use of systematic incremental design modifications, and
5. Use of quick intuitive judgements in making individual design decisions.

Although the above strategy may provide some guidance in applying the interactive graphics system to the transit design process, it is clear that a more-structured approach to interactive problem solving is desired.

The on-line user-time and computer-time costs associated with the IGTDS design process were much lower than anticipated, and the design efficiency characteristics were much better than expected. The error times of the teams averaged only 7 percent of the total on-line time, which speaks well for the ease of using IGTDS, especially considering the short period of time in which the teams were exposed to the system. The computer connect and cpu time figures that characterize the design process were quite reasonable if we consider the complexity of the design problem addressed. In most automated data-processing environments, these computer use figures would translate into relatively modest monetary charges (i.e., on the order of $5 or less per trial design). In terms of design efficiency, IGTDS enabled the teams to design and evaluate 81 alternative designs in 24 h of on-line time and obtain improvements estimated at close to 30 percent over their initial feasible designs.

In summary, IGTDS was found to be easy to use, the application costs were relatively low in terms of both data-base development and system operation, and the design process appeared to be quite efficient in generating design solutions to a relatively complex bus system problem. These findings indicate the strong potential of an interactive graphics system like IGTDS as a practical transit sketch-planning tool.

ACKNOWLEDGMENT

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