INTERACTIVE PROGRAMMING SYSTEM FOR TRANSPORTATION PLANNING

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A major need of the transportation planner is for a system for efficiently managing, analyzing, and updating the volumes of detailed data used in multimodal transportation planning. Without fast, inexpensive methods of analyzing data, the planner simply cannot respond quickly enough to local community needs for an adequate range of transportation design alternatives. The Interactive Planning System (IPS), developed as an extension to the Urban Mass Transportation Administration Transportation Planning System (UTPS), has been designed to meet these needs by providing a time-sharing operating system that eventually will make all of the UTPS software tools available to the planner in a convenient, interactive framework. To accomplish this IPS incorporates 3 major capabilities: (a) an ALGOL-like command language for interactive computation, display, editing, data management, and initiation of batch-mode processing; (b) an integrated data base that automatically relates planning data to alternative designs; and (c) a graphics software capability for generating maps, charts, graphs, and perspective drawings. The system will be accessible through a low-cost interactive graphics terminal remotely connected to a time-sharing computer.

•THE URBAN Mass Transportation Administration (UMTA) since early 1972 has been working actively on a program to improve the effectiveness of urban multimodal transportation planning tools. The primary product of the program is a set of improved analytical techniques and computer-based planning tools designed to assist state and local governments in determining needs and evaluating proposals for transit and highway improvements in urban areas of the United States. This set of tools, called the UMTA Transportation Planning System (UTPS), currently consists of a series of batch-oriented programs for use on the IBM 360/370 series of computers. More recently, UMTA has been involved in upgrading the UTPS package to include an interactive data-browsing, data-manipulation, and graphics-display subsystem called the Interactive Planning System (IPS). Its purpose is to make the computer more accesible to transportation planners and analysts. These workers have desperate needs for systems that will help them

1. Manage large masses of planning data;
2. Efficiently examine, analyze, and update data; and
3. Quickly generate graphs, charts, and maps to display the results of planning analyses.

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A major need of the transportation planner is for a system for managing the volumes of detailed data used in multimodal transportation planning. Current batch-processing methods place on the planner all the burden of manually organizing the assembly, analysis, processing, and display of these data. For all but the simplest of planning projects, these processes are complex, highly interrelated, and composed of a multitude of discrete steps, many of which must be repeated to correct errors and adjust results. A second major need, which also is not met with batch-processing techniques, is for a system for efficiently examining, analyzing, and updating the data and displaying results. Without fast, inexpensive methods for analyzing data, the planner simply cannot respond quickly enough to local community needs for an adequate range of transportation design alternatives. The planner also needs a versatile technique for creating pictorial representations of data during the planning process. Graphic outputs are necessary to expedite the analysis of data and to aid in the comprehension of results. Cut-and-try techniques frequently are required to develop plots or charts that are suitable for presentation. With batch-processing techniques, this is time consuming and difficult. An interactive technique that can be used to both generate charts and maps and modify them in cut-and-try fashion until they are satisfactory is needed.

The purpose of IPS is to meet these needs. A more detailed description of objectives including data-browsing capability and data-base design, has been given by Dial et al. (1). The development of requirements and design concepts to meet these objectives is based partially on earlier work by Ruiter and Sussman (2) and Gur (3, 4, 5), who developed the INTRANS-BROWSE system for analysis and display of zone land use data. IPS has been designed for use by the trained transportation planner and is intended to be easy to understand and apply by new users without loss of power for more experienced users. IPS should be operable from a variety of terminals [teletypes; direct-view storage-tube (DVST) terminals, such as the Tektronix 4012; and intelligent graphics terminals such as IMLAC] with the same basic protocol. It should be possible to transfer IPS from one computer to another with minimal programming effort and, above all, without effects on the command structure and operational characteristics of the system.

Initially, IPS will be used for interactive manipulation and analysis of input data for UTPS batch runs and for further analysis and graphic display of UTPS program outputs. This method of operation is dictated by the high computer requirements of the current UTPS models and programs. New models, particularly those that apply to sketch planning, that will be more suitable for interactive execution are under development by UMTA. These models will be incorporated directly into the IPS subsystem of UTPS when they are completed.

DESCRIPTION

The capabilities of IPS are shown in its 3 major components:

1. A command language for interactive computation, display, editing, data management, and initiation of batch-mode processing;
2. An integrated data base that automatically relates planning data to alternative designs; and
3. A graphics software capability for generating maps, charts, graphs, and perspective drawings.

With its ability to perform both interactive and batch-mode functions, IPS assumes the role of an operating system or host, making all of the UTPS software tools available to the planner in a convenient, interactive framework. The relationship of the IPS host to the data base, current UTPS models, and future interactive models is shown in Figure 1. The host is supported by a direct-access data base containing land use, trip-matrix, network, picture, command-language procedure, report, and card-image files. Regional land use, matrix, and network data are organized as vectors, are indexed by planning zone or node, and have 1 vector for each attribute. These vectors, in fact, usually are called attributes. Some examples are zone population, node coordinates, and trips from one zone to all other zones. Attributes, pictures, procedures, and reports are called file members; each is directly accessible and subject to well-defined operations. This file organization harmonizes with both interactive and batch-processing requirements. Moreover, it is functionally adapted to the kinds of operations that interest the planner.

The planner is able to access planning data and use IPS through an interactive-graphics terminal remotely connected to a central time-sharing computer by means of a 300 or 1200 Baud full duplex dial-up telephone line. The typical terminal has an American National Standard Code for Information Interchange (ASCII) keyboard and a DVST that saves the display until it receives an erase command. Alternatively, the more versatile refresh-type cathode ray tube (CRT) equippped with a small minicomputer can be used to store the display. In addition, the terminal is equipped with a hard-copy unit and an optional graphics tablet for input of graphics data. The hard-copy equipment permits the user to make immediate photographic copies of the DVST-CRT display.

EXAMPLE

The capabilities of IPS to aid in the transportation systems analysis process is illustrated in the following cases. Of particular interest is the method used by the planner to organize the data. Let us suppose that a transportation planning study is being conducted for an imaginary city called Hometown, U.S.A. The base year is 1973, and dual-mode and express-bus alternatives are being considered for years 1980 and 1985. The planner has assembled base-year data and has made initial estimates of future-year land use and total trip data and is ready to update base-year networks to reflect the desired alternatives. By using the data management capabilities of IPS, the planner already has organized his or her files and labeled them with plan labels as shown in Figure 2. The files associated with plan label hometown contain land use and trip data; those associated with alternative plans hometown·express bus and hometown·dual mode contain mainly network data.

At this point, the planner wishes to study the forecast data further and construct the future-year network alternatives. By using a low-cost interactive-graphics terminal remotely connected to a time-sharing computer, the planner begins an IPS session by typing the command

```
use (hometown.express bus)
```

This tells IPS to use data files accessible under plan label hometown·express bus or, if not available there, under its ancestor plan hometown. For example, attributes in a land use file labeled land use : hometown now will be automatically accessible to the user by merely stating attribute name.

The planner is now ready to begin analysis. First, he or she projects zone-per-person automobile ownership and labels it autos owned by typing the ALGOL-like command

```
autos owned := autos.1980/population.1980
```

The terms autos.1980 and population.1980 are zone attributes (in the data base) that forecast 1980 zone automobile registrations and population respectively. IPS performs this calculation by dividing each element of the autos.1980 attribute by the corresponding element of the population.1980 attribute. The result is saved temporarily in a work space.

Next, the planner plots per-person automobile ownership versus projected income on the CRT screen with the command

plot (income.1980, autos owned)

IPS automatically draws axes to a scale determined by the data, enters the names of the attributes plotted, and draws the plot. In a typical case this takes 10 to 15 sec (most of this time is required to transmit the picture from the computer to the terminal).

The planner finds that the plot fails to compare satisfactorily with a corresponding base-year plot apparently because of 1 or 2 unexpectedly low zone-income figures. To investigate this problem, the planner enters the command

if income.1980 < 1000 then income.1980 else skip

IPS responds by displaying a list, by zone, of average zone incomes less than $1,000/year. The calculation is performed by automatic iteration over each zone of the attribute; elements failing the test are skipped. On examining the display, the planner sees that zones 25 and 26 are incorrect and enters the following corrections by indexing the income attribute:

income.1980[25] := 5250

income.1980[26] := 7300

After repeating the plot and making some further checks, the planner is ready to construct the 1980 express-bus network by using the UTPS batch-mode program UNET. Because the planner wants the new network file to be identified with the 1980 express-bus alternative, he or she names a new plan with the command

create (hometown.express bus.1980)

This supersedes the initial use command but continues to permit access to data labeled hometown·express bus (or hometown). If the planner now updates such data, he or she can reference the updates under the new plan, but the original data still can be referenced by invoking the parent plan. The new plan structure is shown in Figure 3. The planner now issues the command

submit (unet)

Parameters and options required by program UNET will be requested by the use of interactive dialogue by IPS, and then the program will be executed independently at some later time depending on the priority requested by the planner. The output network file will be identified with the label hometown·express bus·1980. This is shown in dotted lines on Figure 3. At this point, the planner may wish to sign off and return later to examine UNET output. However, the results of calculations early in the session are still in the work space. The planner can store all results or only those needed to be used again. For example, the planner can store a land use attribute in the land use file associated with the current plan by typing the command save (autos owned, land use)

and then release the work space by signing off, or the planner can save the work space by the command

save work space

and retrieve it when he or she returns to the terminal. These examples are simple, even prosaic, but they illustrate the potential savings in time, effort, and cost that interactive planning techniques can provide.

BASIC INTERACTIVE PLANNING SYSTEM COMMANDS

Computation and Output

The IPS user performs operations on the data and generates maps and graphs based on the data by typing commands at the terminal. Normally, statements entered at the terminal are executed immediately by the computer. For example, when the user enters

autos owned := autos/population

the computer examines the statement, and, if any errors exist, reports them or, if no errors exist, computes the expression on the right side of the symbol := and assigns the computed value to the variable named on the left side of the symbol but does not display the result. In this example, autos/population is evaluated, and the result is assigned to the variable autos owned. The response time of the computer is sufficient to allow the user to type in statements almost as quickly as he or she desires. The set of operations available to the IPS user for constructing expressions are the basic arithmetic operations of addition, subtraction, multiplication, division, and exponentiation; comparison operations; and a set of functions to compute dot products, square roots, logarithms, and trigonometric functions; and Boolean operations such as AND, OR, and NOT. Table 1 gives a list of these operations (and others to be described). The IPS command in the previous example has the form of an assignment statement:

variable := expression

However, the user may enter a statement consisting of only an expression [such as 5*sqrt (27)or autos*2.7]. The computer will evaluate the expression and display the result, which may be a scalar or a vector (attribute) depending on the terms in the expression. This feature permits the user to exercise IPS as a powerful desk-top calculator.

The ability to implicity perform operations on all elements of an attribute is of significant help to the planner using IPS. Of course, operating on selected elements of an attribute by providing a list of indexes also is possible. Thus the statement

a [5, 10-20, 30-last] := 100

would assign the value 100 to the fifth, tenth through twentieth, and thirtieth through

Figure 1. Relationship of Interactive Planning System to data base and models.

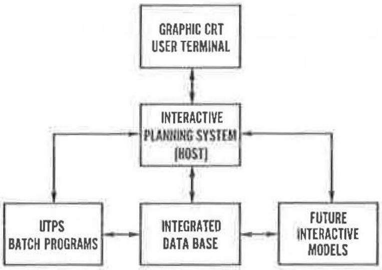

Figure 2. Plan structure for base-year network.

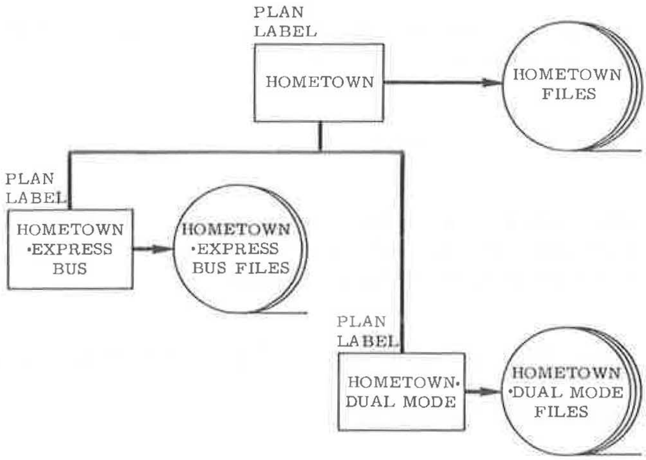

Figure 3. Addition of 1980 express-bus plan.

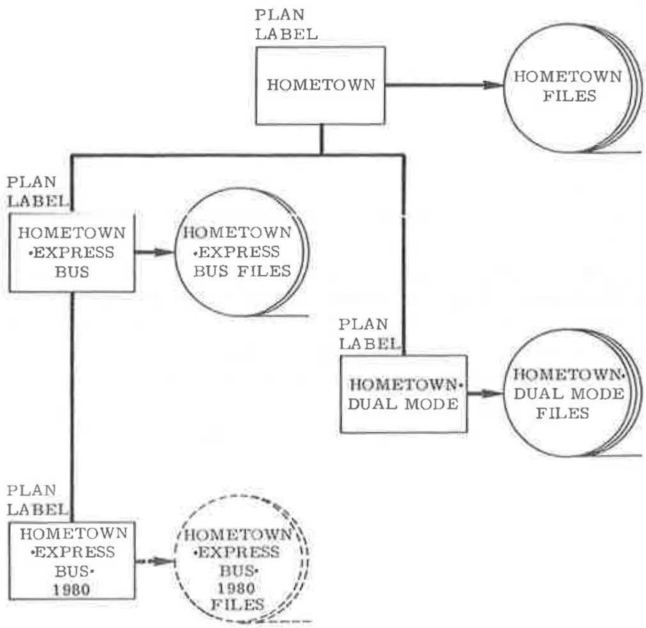

Table 1. Type-specific operations on file members.

File Member	Operation	Operator
Attribute	Arithmetic	+, -, *, /, **
	Comparison	<, >, =, <=, >=, NOT<, NOT>, NOT=
	Vector	Dot Product
	Logical	AND, OR, NOT, NAND, NOR, XOR, IMP, EQU
Picture	Transformations	TRANSLATE, SCALE
	Display	DISPLAY
Procedure	Editing	Insert, delete, replace, and the like
Reports and card-image sets	None	None (initially, standard editors will be used)

last element of the attribute a.

An assignment statement or expression may be executed conditionally by enclosing it in an IF ... THEN ... ELSE construct. For example, in the command

```
if a < b then x := y else x := z
```

if the comparison a < b is true, then the assignment x := y is executed; otherwise, the assignment x := z is executed. If these variables are attributes, then the statement is executed iteratively and the result x may contain elements from both y and z.

Names and Variables

A name in IPS can stand for integer, real, string, or logical variables, or it can stand for a procedure, picture, or report. Variables are single elements, such as scalars, or 1-dimensional arrays, such as attributes. All elements of an attribute must be of the same type. Integer, real, and logical variables are the familiar types used in FORTRAN or ALGOL. A string variable contains a string of up to 256 characters. These may be any combination of letters, digits, or special characters.

Matrices (such as trip and fare matrices) exist in the data base, but, in IPS, they are dealt with a row or column at a time. Thus the command

```
trips from zone.5 := matrix (trip table, 5)
```

would define the attribute trips from zone.5 as the fifth row of a matrix called trip table. (Note that variable names can consist of more than 1 word.)

In keeping with a user-oriented philosophy, no restrictions exist on the use of names for variables and procedures as they do in FORTRAN. More significantly, the IPS user is not required to declare the type or length of the variable. These are attributes of the data rather than of the name of the variable. Thus in the statement

```
a := b+5
```

the type and length of the evaluated expression b+5 will be associated with a after execution of the statement. If b was a real vector of 10 elements, then the command would make a a vector of 10 real elements, each of which is 5 greater than the corresponding element in b.

Procedures

As the planner becomes familiar with IPS, he or she undoubtedly will develop his or her own repertoire of operations for data manipulation and display. To save the planner the tedious task of entering the same set of statements each time he or she looks at a new set of data, IPS permits the planner to construct procedures with a simple editor. A procedure is a named set of statements that can be executed simply by entering the name of the procedure. It can change specified variables in the manner of a FORTRAN subroutine, or it can return a value in the manner of a FORTRAN function. Consider the following example:

```
procedure compare incomes (factor)
   erase
   plot (zones, income)
   new income := factor * income
   plot dashed line (zones, new income)
```

Executing this procedure [by entering compare incomes (factor)] will cause erasure of the CRT, drawing of an appropriate set of axes, drawing of a solid-line curve of incomes for a set of zones, computation of a new set of incomes based on a predictive factor f (this factor could be a single variable or a vector with a different value for each zone), and addition to the display of a dashed line showing the new incomes for each zone. In this example, plot and plot dashed line are part of the repertoire of built-in procedures included with IPS. A user procedure can reference other user procedures as well as IPS procedures. Recursive procedures also are permitted. The example shows another important characteristic of procedures, namely, that they can be made data independent. This means that the previously mentioned procedure operates on the currently defined attribute income by using whatever argument is passed to the procedure as the multiplicative factor.

IPS procedures can contain conditional statements and commands for explicit iteration. These take 3 forms.

1. IF (Boolean expression) THEN (set of satements);
2. IF (Boolean expression) THEN (set of statements) ELSE (set of statements); and
3. WHILE (Boolean expression) DO (set of statements).

Observe that, in a procedure, a THEN or ELSE clause can be followed by a set of dependent statements and is not limited to a single statement as described previously for directly executable commands. In the WHILE ... DO construct, the DO clause is executed repeatedly while the Boolean expression is true. The DO clause, of course, must change the value of 1 or more of the variables in the WHILE clause or execution of the procedure will continue indefinitely. The dependent statements of a conditional or iterative statement themselves can be conditional or iterative statements; that is, the statements can be nested.

IPS syntax depends on differences in indentation to identify the beginning and end of each set of statements in the previous 3 constructs. Thus IPS procedures have an ALGOL-like block structure without requiring the use of ALGOL begin and end brackets. This makes for readable text.

A simple yet powerful editor is provided for entering, testing, and correcting procedures. Its operation is analogous to that provided in advanced time-sharing operating systems.

GRAPHICS

The primary aims of the IPS graphics capability are to provide graphs, charts, and maps that will aid the planner in quickly comprehending data and making the trade-off analyses and judgments required in developing alternative multimodal transportation plans. The long-range aim is to build up a repertoire of graphics tools that will lead to substantially improved transportation planning methods. In addition to generating standard plots and maps on CRT screens, pen plotters, and computer-output microfilm (COM) devices, it is intended to provide a general-purpose language for constructing graphic objects that can be displayed in perspective and to include software tools for development of interactive-graphics techniques. These techniques can be used not only to expedite and improve the generation of graphic outputs but also to open the door to a whole new class of person-machine problem-solving methods that has potential for substantial time and cost savings, greater flexibility, and improvements in quality over existing methods. Work already has been started in applying such techniques (6, 7, 8) and in measuring their effectiveness (9) in transportation systems analysis. As has been shown, no shortage of potential transportation planning applications for interactive-graphics techniques exists (10).

Currently, 3 basic capabilities are included in the initial IPS graphics package, including ability to

1. Generate standard plots and maps,
2. Construct "wire-frame" graphic objects in 3 dimensions and display them in perspective, and
3. Save CRT screen displays in the IPS data base.

The standard plots will include x-y plots, regression line plots, frequency distributions (histograms), pie charts, land use maps, and network plots. These will be implemented so that a simple command such as plot regression (income, auto ownership) will generate a graph with standardized axes the scaling of which is computed automatically from the data. Thus each graph or chart will have a standardized form based on the use of default parameters to permit generation with the simplest possible command. The standard forms can be changed by the use of specification commands that tailor graphs or charts to individual requirements. Commands will be provided to plot zone land use maps by using zone-centroid coordinate and boundary information stored in the data base. The user is planned to be permitted to input boundary information by tracing zone outlines with a graphics tablet and stylus. Techniques for displaying attributes of each zone include display of numerical values, symbols whose sizes are proportional to the numerical values, and zone shading to depict density. This includes symbol-shading techniques (3) and CALFORM line-shading techniques (11).

A general-purpose graphics capability (12, 13, 14) will be provided to permit the planner to create arbitrary 2- or 3-dimensional displays, subject to translation, scaling, rotation, and projective and perspective transformations. The basic tools for constructing these displays will be a set of graphic primitives for drawing lines and points and providing annotations. Defining command language procedures that build up graphic objects from primitives and other previously prepared procedures will be possible. This, of course, will permit the planner to increase the sophistication of standard displays and will also allow him or her to develop displays of actual structures.

To increase user flexibility, building up a display in increments will be possible. Drawing commands transmitted to the display device are recorded in a temporary file called a transformed display file. The user can define a segment of this file by issuing a PICTURE command. This segment, or picture, will include all pieces of the display drawn since the last PICTURE command or since the display was started if no PICTURE command has been given previously. These pictures are most useful in a refresh-type display because the display can be varied readily by turning on or turning off the individual pictures that make up the display. When the user is satisfied, he or she can take a "snapshot" of the display by giving a SAVEPIC command. This collects and combines all the turned-on segments of the display file into a single picture and saves it in the data base. Then the user can issue a CLEAR command to erase the screen and the display file and begin constructing another display or issue a DISPLAY command to retrieve the saved picture and redisplay it on the CRT screen or another device such as a plotter. An additional feature is that any defined picture can be translated and scaled for inclusion as part of another display.

FILE SYSTEM (INTEGRATED DATA BASE)

The IPS file system includes separate files for each of the 6 basic types of file data: land use attributes, matrices, network attributes, pictures, command-language procedures, and text matter including reports and card-image data. To file members of each of these types, the planner may assign descriptive names, such as population, link volumes, or corridor zone map. The range of operations to which file members are subject has been given in Table 1. File members also are subject to LIST and DELETE utility operations. Retrieval of a file member occurs automatically on reference to its name. Retrieval is facilitated by a master directory file that contains the name of each file, a list of its members, and pointers to each member. The directory file also keeps track of backup copies of file members that are saved when a file member is corrected or deleted.

A novel feature of the directory file is its ability to let the planner organize data under labeled planning alternatives. The asumption is that the process of creating and evaluating alternative transportation plans can be represented effectively as a tree-structured modeling process in which plans and subplans are developed at ever-increasing levels of detail and specificity. Although the plan structure illustrated in the example described previously was quite simple, the planner is free to develop more elaborate structures in accordance with the complexity of his or her transportation planning problem.

The planner generates a plan structure by using the CREATE command. When this command is invoked, it generates and activates a new plan that becomes a successor of the plan that was active before the CREATE command. A previously created plan can be reactivated by means of a USE command.

Data files developed or modified when a plan is active are said to belong to that plan and can be accessed whenever the plan is active without specifying the plan label. If an old file generated under a predecessor plan has 1 or more of its file members modified, then new members are created to reflect the modifications. The new members are identified under the new plan, but the corresponding old members are still identified and accessible under the old plan. Unchanged members are accessible under either plan. This is so because the system automatically creates a new logical file that physically contains the modified members but has only pointers to the unchanged members. The old file could itself be a similar logical file or could, in fact, be the original file. The planner can always reference it by using an appropriate USE command identifying its plan label. Utility commands are provided to list the structure of plans and logical files created by the planner.

We have described the internal world of the integrated data base, but we must still provide for communication with the outside world. That is, to readily add outside files to the IDB or to copy internal files onto external media, such as a magnetic tape, must be possible. This is accomplished with INPUT and OUTPUT commands that transfer either complete files or specific file members from one world to the other. However, binary external files that do not conform to UTPS formats cannot meaningfully be transferred into the integrated data base (IDB). These must first be processed either through standard UTPS conversion routines or by means of user-coded routines.

STATUS OF INTERACTIVE PLANNING SYSTEM

The overall functional specification of IPS has been completed (15). Currently, 2 parallel efforts are under way in preparation for IPS implementation. First, a skeletal subsystem of IPS is being identified for initial implementation. The objective is to give planners a system that can be used to perform basic mathematical operations, can support simple user defined procedures, can interface with a direct-access data base, and allows the generation of basic plots and simple 2-dimensional wire-frame drawings. The more esoteric features described in the functional specification are anticipated to be added to the skeletal system incrementally. The second effort is implementation of the graphics package to be used for IPS on a PDP-10 computer. The package selected for IPS is the graphics compatibility system (GCS), a terminal- and computer-independent system developed at the U.S. Military Academy (16). GCS initially will support several of the more common alphanumerical terminals, the Tektronix 4010 series of direct-view storage-tube terminals, and the IMLAC PDS-1 intelligent graphics terminal.

The interactive portion, particularly the command language of IPS as currently defined, is intended primarily for use with a direct-view storage-tube terminal. As a continuation of the functional specification, a trade-off study is being performed to determine how user interaction might be improved through some of the more dynamic techniques of a low-cost, intelligent, refresh-type terminal (such as IMLAC). The possibility of having the intelligent terminal share some of the computational workload with the central processor for both improved response and reduced cost of operation also is being investigated.

The initial version of IPS is expected to be available for field testing early in 1976. The results and experience will aid in determining priorities for further development and improvement of IPS and for development of instruction courses. The field-testing program also will provide information for determining benefits and costs of using IPS in transportation planning studies of varying size and scope.

SUMMARY

IPS is a new transportation planning tool that combines powerful computational and graphic capabilities. It will provide a framework within which the planner can efficiently examine and analyze land use and other transportation-related data, execute batch-processing models, and study results.

Although IPS command language syntax is similar to ALGOL, the interactive features are more comparable to those of APL. IPS has been designed with ease of use by the transportation planner (rather than the experienced computer programmer) foremost in mind. The command structure, the user-defined procedures, the data-retrieval mechanisms, and the graphics operations were tailored to free the user from unnecessary and cumbersome details through carefully designed default options and considerable built-in intelligence on the part of IPS. IPS provides the novice user with a minimal set of simple and easily learned commands that allow data browsing and analysis to generate meaningful results. At the same time, IPS has the power and flexibility needed by the experienced user to tailor the system and its outputs to his or her particular requirements.

IPS will interface with a structured, plan-oriented data base. This data base in turn will provide input to and receive output from the currently existing UTPS battery of transportation planning and analysis programs.

The IPS system obviously is not ideal because it does not provide for interactive execution of planning models. Unfortunately, existing models for transportation planning require large amounts of processing time and thus do not lend themselves to an interactive mode of operation. There has been recent interest in developing new planning models, particularly in the long-range (sketch-planning) area, that use smaller sets of input data and require less computation. As these models become available, interactive versions will be incorporated into IPS. This will lead to a fuller realization of the potential benefits of an interactive planning system. Decision makers will be able to ask a planner questions, and the planner, through use of IPS, will be able to respond quickly enough in a format understandable by the decision maker to favorably affect the decision-making process.

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REFERENCES

1. R. B. Dial, P. S. Loubal, E. L. Luther, and G. J. H. Brown. A Procedure for Long Range Transportation (Sketch) Planning. International Conference on Transportation Research, Bruges, Belgium, June 18-21, 1973.

2. E. R. Ruiter and J. M. Sussman. Interactive Computer Graphics for Transportation Analysis: Cost Effectiveness and Initial System Design. Massachusetts Institute of Technology, Rept. 71-46, Dec. 1971, 82 pp.
3. Y. Gur. A Computer System for Interactive Analysis and Planning of Urban and Transportation Systems. College of Engineering, Univ. of Illinois at Chicago Circle, Technical Rept. 1, May 1972, 46 pp.
4. Y. Gur. INTRANS-BROWZE Version 1-2, Interactive User Manual. College of Engineering, Univ. of Illinois at Chicago Circle, Technical Rept. 2, Jan. 1973.
5. Y. Gur. INTRANS and BROWSE, An Interactive Graphics System for Planning and Related Data Analysis. Highway Research Record 455, 1973, pp. 23-35.
6. M. H. Rapp. Planing Demand-Adaptive Urban Public Transportation Systems: The Man Computer Interactive Graphic Approach. Urban Transportation Program, Univ. of Washington, Research Rept. 71-4, 1972, 203 pp.
7. M. H. Rapp. Interactive Editing of Transportation Networks. Urban Transportation Program, Univ. of Washington, Research Rept. 4, 1970, 35 pp.
8. Interactive Graphic Transit Design System User's Manual. In UMTA New Systems Requirements Analysis Program, Peat, Marwick, Mitchell and Co., Rept. URD. PMM. 73. 1. 1, March 26, 1973.
9. J. B. Schneider and D. L. Porter. Assessing the Utility of a Interactive Graphic Computing System: A Case Study of a Transportation Systems Design Problem. Urban Transportation Program, Univ. of Washington, Research Rept. 73-2 (UMTA-URT-3-73-2), 1973, 17 pp.
10. J. B. Schneider. Interactive Graphics in Transportation Systems Planning and Design. Proc. of seminar at Battelle Seattle Research Center, Oct. 31-Nov. 1, 1973, Departments of Urban Planning and Civil Engineering, Univ. of Washington, 95 pp.
11. Laboratory for Computer Graphics and Spatial Analysis. Graduate School of Design, Harvard Univ., program description and availability memorandum for CALFORM, July 1972, 6 pp.
12. W. M. Newman and R. F. Sproull. Principles of Interactive Computer Graphics. McGraw-Hill Book Co., 1973, 607 pp.
13. W. M. Newman and R. F. Sproull. An Approach to Graphics System Design. Proc., Institute of Electrical and Electronics Engineers, New York, Vol. 62, No. 4, April 1974, pp. 471-483.
14. W. M. Newman. Display Procedures. Communications of ACM, Vol. 14, No. 10, Oct. 1971, pp. 651-660.
15. Functional Specifications for an Interactive Planning System. Peat, Marwick, Mitchell and Co.
16. Graphic Compatibility System (GCS) Programmer's Reference Manual. Instruction Support Division, U.S. Military Academy, Rept. 74-2, April 1974.