INTERACTIVE COMPUTER GRAPHICS IN TRANSPORTATION

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This paper considers the potential role of interactive graphics in transportation systems analysis. The general characteristics and benefits of interactive graphics systems are explored, and a survey of existing systems is presented. In particular, applications in the transportation and planning fields are reviewed, and conclusions on the use of interactive graphics systems for transportation systems analysis are presented.

•THE FIELD of transportation systems analysis is becoming increasingly complex. The number, size, and scope of the transportation systems the profession is being called on to consider are growing exponentially. Public awareness of the political, social, and economic impacts of these systems is likewise increasing. It is clear that the analyst needs help as he considers the many alternatives open to him in making transportation decisions.

One largely unexplored mechanism for assisting the transportation analyst in his decision-making is interactive computer graphics. The purpose of this paper is to consider the possibilities of interactive computer graphics for use in the transportation field. To accomplish this, the general characteristics and benefits of interactive graphics systems are explored, and a survey of existing production interactive graphics computer systems is presented. A limited benefit model highlighting the important aspects of such systems is introduced.

Then, applications of interactive computer graphics in the transportation and planning fields are reviewed. Based on the above, conclusions on the use of interactive graphics systems in general and in transportation in particular are presented.

BACKGROUND

Interactive computer graphics systems have a very short history. The initial major pioneering efforts took place at M.I.T. and General Motors in the early 1960s. During this period, Ivan Sutherland experimented at M.I.T. with a cathode ray tube (CRT), light pen, function console keyboard, and the experimental TX-2 computer. This effort led to the SKETCHPAD system, with applications in the areas of drafting and structural analysis (25). During the same period, the Design Augmented by Computer (DAC) project was under way at General Motors. This project led to the development of DAC-1, a system used for automotive design (11). Following these initial efforts, interactive graphics systems were developed by industry and universities. A number of these efforts are discussed in this paper.

Although a great deal has been accomplished in the 10 years since Sutherland's original breakthrough, the potential of interactive computer graphics in production use is largely unrealized. There have been a few efforts to utilize interactive graphics in production work, but these have tended to be isolated examples.

The principal reasons for the slow development of interactive computer graphics were

1. Hardware costs—Interactive displays tended to be extremely expensive in terms of the display device itself, support hardware, and the amount of machine time used during operations.
2. Software support—Interactive graphics applications are only meaningful if they are integrated with a well-designed application software system, and few well-designed

application packages existed with which interactive graphics capabilities could be integrated.

3. Man-machine interaction—The application of interactive graphics was not well understood. Analysts with some computer background were oriented toward batch processing computer operations. The introduction of such concepts as remote job entry, time sharing, plotting, engineering input-output stations, and computer graphics radically changed the environment between the analyst and the computer. Significant questions were raised relating to where, how, and to what extent interactive computer graphics fit in the decision-making process.

The past 10 years can be viewed as the decade of research and experimentation in computer graphics. This period corresponds to the decade of 1950-1960 when computers were first introduced. The potential of computers was acknowledged, but the realization of that potential was a difficult, lengthy, and expensive process. A dramatic change occurred between 1950-1960 and 1960-1970. Hardware costs declined, and processing capabilities increased. Applications evolved from simple numerical computations to large-scale information systems. The analyst began using computers as a real tool in decision-making rather than as simply a substitute for the slide rule and desk calculator.

The same kinds of changes are now occurring with regard to interactive computer graphics. Significantly less expensive display devices are available. Application packages that can utilize interactive graphics capabilities are being developed. The analyst is beginning to understand better an interactive graphics environment and how the many capabilities are best used. All in all, these changes point to increased use of interactive computer graphics over the next decade. Given that, it is useful to examine where we have been and what has been accomplished in the field to date. In this light, this paper proceeds to establish (or, more accurately, review) the perceived advantages of interactive graphic systems and then survey existing graphics systems with respect to these advantages.

DEFINITIONS AND CHARACTERISTICS

A useful definition of computer graphics given by Siders (22) is as follows: "The term . . . refers to the concept of man communicating with a computer by means of graphical symbols such as lines, curves, dots, and so forth." However, interactive graphics implies characteristics above and beyond this definition. In this paper, the following considerations pertain: Computer graphics is interactive when man and computer may engage in a dialogue. In particular, interactive computer graphics involves both graphical output and graphical input. Computer graphics is interactive when the graphics capabilities can communicate with an analysis system. ("Analysis system," as used here, refers to the computing capabilities that can exist without computer graphics, e.g., a structural analysis system, but that are enhanced if used with computer graphics.) Through the graphics system, the user has control over the operation of the analysis system, and the user can observe, often dynamically, the progress of the analysis system as it proceeds through its runs.

An interactive graphics system may be interactive in one or the other or both of the senses described. The desired degree of interaction depends on an evaluation of the added costs of highly interactive hardware and software systems versus the added benefits of these systems. These benefits will, of course, vary from problem area to problem area. However, in general, they can be classified in three general catagories: time savings, the development of better alternatives, and cost savings.

Time Savings

A number of authors have quoted various amounts of time savings associated with the use of computer graphics systems. Typically, these quotations vary from a ratio of time with computer graphics to time without computer graphics of anywhere from $\frac{1}{2}$ to over $\frac{1}{1,000}$. This wide range can be narrowed by differentiating between direct time saved and elapsed time saved. Direct time savings can be expressed as the ratio of the time required to perform a specific task entirely with a computer graphics system to the time required to perform the same task entirely without the use of computer graphics. Typical ratios for direct time savings are in the range of $1/6$ to $1/1{,}000$. Similarly, elapsed time savings can be expressed as the ratio of the total time required to complete a major design effort with the use of computer graphics to the total time required when computer graphics are not used. Typical ratios for elapsed time savings are in the range of $1/2$ to $1/8$.

Development of Better Alternatives

Computer graphics can lead to better solutions to engineering problems for two major reasons. First, the direct time advantages described in the previous paragraph allow the engineer to do more experimentation. In problems that involve trial-and-error analysis, as most engineering problems do, the engineer can explore a wider range of potential solutions. The probability of finding a better solution is therefore much greater when the engineer uses some portion of the time savings available to him to explore his "solution space" more carefully.

Second, the engineer is more likely to obtain an intuitive "feel" for the problem he is observing when he is able to make modifications almost instantaneously and to observe the results of these modifications in a graphical display. Given this "feel," the engineer is more likely to propose better solutions to his problem. This phenomenon has been described by many as "synergy," or the 2 + 2 = 5 effect, in which the capability of the engineer to solve problems heuristically (the trial-and-error approach) is combined via graphics communication to do a better job than either can do separately.

Cost Savings

In most applications, computer graphics will ultimately be evaluated by using monetary measures. In the private firm, the measure is usually the contribution to increased profits. In the case of a public agency concerned with transportation planning, the measure should be net benefit or net cost savings. This type of evaluation, however, must be based on a definition of costs and benefits that is broad enough to include all who will be ultimately affected, both positively and negatively, by a computer graphics system for transportation planning. Some cost savings will be directly felt by the public agency that has at its disposal a transportation graphics system. Others, such as reduced operating costs on highways due to the design of better alternatives, will be less directly felt but no less important in the evaluation of graphics systems.

The advantages discussed in the previous paragraphs can be expressed as cost savings. Direct time savings are reflected in reduced engineering costs. Also, engineers who are able to continue work on a project, without time-out to wait for computer output and drawings of the results, can keep their trains of thought in motion with no delay to recall and rethink previous work toward a solution.

Elapsed time savings reduce the time from project initiation to project completion. In the case of transportation facilities, this normally means that travel cost or time savings or both will begin sooner for the users.

Better alternatives can also result in significant cost savings. Alternatives may be better in that they cost less to construct. And, as mentioned above, alternatives may be better in that they result in lower operating costs.

An additional potential area of cost savings also exists: Computer graphics can reduce the overhead cost of engineering and planning work by reducing the number of hard-copy documents, both graphic and tabular, that must be produced and maintained. In some engineering operations, about one-half of the wages and salaries are devoted to drafting. If the analyst can see, almost instantaneously, the information he needs on a computer graphics display, he can do without many of the hard-copy displays and computer listings that tend to clutter his working space and that cost significant amounts to produce and maintain.

We have discussed the potential advantages of computer graphics without being specific in terms of existing or proposed systems. Also, we have ignored the disadvantages or costs of computer graphics. These considerations are included in the remaining sections of this paper, where specific existing systems are discussed.

EXISTING SYSTEMS IN PRODUCTION USE

The existing interactive graphics systems with engineering applications, for which some information on costs, benefits, or overall cost-effectiveness is available in the literature, are discussed in this section. For the evaluation of the systems to be valid, we felt that they should be working versions rather than academic systems, research efforts, or system proposals. At the present time, the number of such systems is very limited. This is undoubtedly due to the relatively short period of time during which interactive graphics hardware has been generally available, the even shorter time that the required software (plotting packages, communications packages suitable for interactive graphics, and time sharing) has been available, and, until recently, the high costs of both hardware and software.

It was hoped that one or more systems with transportation planning capabilities would be found that met these criteria, but no such systems were found. The major systems meeting the criteria have all been developed and used by industrial concerns.

General Motors

The first major development of an interactive graphics system by an industrial firm was the DAC-1 effort, begun by General Motors in about 1959 and not announced until 1964 (11). The hardware for the system was built by IBM to GM specifications and later became the prototype of the IBM 2250 console. The GM system has been developed to be useful in various portions of automotive design, including body styling, crash simulation, and automatic drafting. Elapsed time savings for the complete process of automobile design of 2 years using DAC-1 versus 4 years using noncomputer graphics procedures have been quoted. Based on the experience with DAC-1 using second-generation computers, the system has been modernized to form DAC-2, a system based on the IBM 360/67 and 360/65 computers and 2250 graphics terminals. DAC-2 is now in normal production use, and present plans call for expanding the system as time goes on.

Lockheed-Georgia Company

The Lockheed-Georgia Company has been among the leaders of the aerospace firms in developing and applying computer graphics (8, 17). Its prototype work was done by using CDC Digigraphics hardware. The production version initially used DEC 340 devices and later IBM 2250 devices. The first working capability was the generation of automated machine tool control tapes. Interactive computer graphics was used, replacing the standard Automatically Programmed Tools (APT) programming language, to prepare the tapes, which control the manufacture and finishing of small parts. This capability was first available in 1965 and has been found to reduce the tape generation elapsed time from a week to 24 hours. In addition to the time savings, major benefits of the capability are that it eliminates the need for programming expertise in the APT language and results in fewer rejected parts due to faulty machine control tapes.

Following this initial success with interactive graphics, Lockheed-Georgia has gone on to add a number of capabilities to the system. Some of these are as follows:

1. Structural analysis of airframe sections,
2. Generation of airplane fuselage surfaces,
3. Design of printed circuit layouts,
4. Simulation of aircraft landings,
5. Interpolation and data smoothing of three-dimensional airframe test data (computer graphics has reduced this task from being a job of 1 or 2 weeks to one of a few minutes), and
6. Placement of parts on large standard-size surfaces.

Mobil Oil Company

Using IBM 2250 hardware, Mobil Oil Company has developed interactive computer graphics capabilities (9) in the following areas:

1. Design of fractionating towers (computer graphics has reduced the elapsed time for this task from months to hours and has resulted in more efficient and cheaper designs),
2. Analysis of seismic data for oil exploration, and
3. Layout of pipeline complexes and control systems.

McDonnell Douglas Corporation

Among the extensive interactive computer graphics systems surveyed, McDonnell Douglas is unique in that it was developed largely by its ultimate users in an open-shop environment (9, 14). This approach has led to a wide range of capabilities:

1. Input and editing of three-dimensional aircraft shapes with direct time savings of 1 month to 10 minutes,
2. Structural analysis,
3. Analysis of airfoil performance with direct time savings of 6 weeks to minutes,
4. Simulation of flight paths with direct time savings of from 4 weeks to 1 hour,
5. Scheduling of projects using PERT,
6. Prediction of passenger seat-miles using an econometric model,
7. Comparison of the costs of surface and air freight in a distribution cost model with direct time savings of days to minutes,
8. Scheduling of airlines,
9. Analysis of airport runways,
10. Continuous system modeling program with graphic output, and
11. Calculation of the return on investments.

This wide range of graphics capabilities includes a number that are of a type foreseen in a transportation graphics system, especially items 6 through 11.

The quantitative information available for the systems described in this section, basically direct or elapsed time savings, is only part of the picture of their true cost-effectiveness. In each case, a number of intangible benefits, including competitive advantages and the ability to improve products and reduce their costs, are highly significant but not quantified. In fact, in spite of the impressive time savings that have been observed with these systems, some authors believe that the development and use of existing computer graphics systems can only be justified by taking into account the intangible benefits; direct time benefits are not believed to be enough to justify the system costs that have been involved in existing systems (9, 14).

The fact that computer graphics development is continuing in industry indicates that it is the view of management that these systems are significantly cost-effective, although whether these gains are perceived as short term or long term is unclear.

A BENEFIT MODEL

A useful mechanism for summarizing the preceding sections is a simple benefit model. This model shows the basic relation that exists between interactive computer graphics costs and benefits:

$$TB + IB + DCB$$

where

TB = total benefit of using interactive computer graphics,
IB = other intangible and indirect cost benefits including benefits due to elapsed time savings, to better and/or more economical products or alternatives, and to efficiencies in the design process, and
DCB = direct cost benefits.

IB is, by its very nature, difficult to quantify and clearly will vary from application to application. It is obvious, though, that IB can be very large in cases where the product has a high value, leading to meaningful savings when the product is improved. If one considers the products to which production interactive computer graphics systems have been applied (automobiles, airplanes, fractionating towers, airport design), it seems clear that the value of the product is implicit in the decision to use the technique.

DCB, in dollars per year, is somewhat simpler to quantify.

$$DCB = T\left[W_m - F\left(W_g + VCC + \frac{ACC + FC}{D}\right)\right]$$

where

- T = total time spent on application without graphics, hours/year;
- W_m = wage rate for manual work in application area, dollars/hour;
- W_g = wage rate for work at graphics console in application area, dollars/hour;
- F = time saving rate using graphics = (time using graphics)/(time using manual methods);
- VCC = hourly variable computer-related and console-related computer costs for graphics applications, dollars/hour;
- ACC = annual fixed console-related and computer-related computer costs due only to graphics, dollars/year;
- FC = annual fixed costs for graphics software and overhead, dollars/year; and
- D = maximum console usage rate, hours/year.

D applies to all applications using a system, whereas the formula itself refers to a single application. Clearly, $D \geq TF$.

Although we stress that it is erroneous to consider only DCB in evaluating a graphics system, the expression for DCB is useful in that it illustrates the following points:

Due to the fixed costs, which include developments and can be very high [O'Neill (14) estimates 60 man-years of development effort in the McDonnell Douglas system], the total time spent on work in graphics application areas (T) must be high to ensure positive cost benefits.

The time saving rate using graphics must be significantly less than (manual wage rate)/(graphics wage rate + fixed and variable console costs) or

$$F = \frac{W_m}{[W_g + VCC + (ACC = FC)/D]}$$

If the rate is equal to or greater than this quantity, cost benefits will be negative. As manpower costs increase over time, the required value of F will increase, and more systems will become cost-effective.

Console costs can be critical. Assuming that console and computer costs continue to decrease, as they have in the last 3 or 4 years, more and more graphics applications will change from negative to positive direct cost benefits.

As more experience is gained with the design and implementation of graphics systems, the fixed costs (FC) of these systems can be expected to decrease. The availability and use of standard packages of system and utility programs will also cause a decrease in fixed costs. These changes will have a direct positive effect on the direct cost benefits of graphics systems.

In summary, based on this simple model of the direct cost benefits of computer graphics systems, graphics systems can be expected to become increasingly cost-effective as (a) manpower costs rise, (b) console costs decrease, and (c) development costs decrease.

EXISTING SYSTEMS WITH APPLICATION TO TRANSPORTATION AND PLANNING

The previous sections have reviewed the general state of the art in interactive computer graphics and have, it is hoped, given the reader an understanding of the conditions under which the concept is a cost-effective one. Before we go on to draw any conclusion on the relevance of this technique to the field of transportation, however, it is first useful and necessary to review the state of the art of computer graphics applications related to transportation and planning. These systems either are at the proposal state, have only been used in a test or prototype environment, or are in production use although no information on their cost-effectiveness is available.

Highway Design Systems

The first highway plotting using digital plotters in the United States was done at the Department of Civil Engineering at M.I.T. in 1961 (20). Since that time, a large number of programs have been developed, and many organizations have incorporated comprehensive plotting packages into production usage. Packages normally include geometry, profile, and cross section routines, and, in addition, many include network and traffic plotting capabilities. Existing packages are not interactive, and usually the output device is a paper plotter. Organizations using these capabilities include nearly every state highway department and many consultant firms who do highway design work.

The earliest highway perspective plotting was performed by Nordick, a European engineering firm, in the early 1960s. In recent years, a number of organizations have developed perspective drawing programs, some of which include a "scene walking" capability that permits a user to "drive" along the proposed roadway in a simulated fashion.

At the present time, interactive graphics systems for highway design are in the proposal, system design, and prototype stage. The proposal for the California Division of Highways systems (2) contains the following summary of estimated annual savings for a system of 166 storage device CRT terminals:

Item	Time (million hours)
Present design hours	4.15
Design hours with graphics	3.44
Design hours saved	0.71

Item	Cost (million dollars)
Wages saved ($7.25/hour)	5.15
Additional computer charges	1.95
Annual cost savings	3.20
Hardware acquisition	1.48
System development	0.58

In addition to the time savings quantified, additional savings due to higher quality design were predicted but not quantified.

Urban Planning

The most significant area in which computer graphics has been applied to urban planning problems is computer mapping. A survey of the systems available is given in Goldstein, Wertz, and Sweet (7). All systems surveyed were non-interactive. A number of research-oriented or prototypical interactive graphics systems with applications to urban planning now exist. Some of the more interesting of these follow.

DISCOURSE—This is a system (15) that allows the planner to describe an area divided into a grid by specifying the attributes of the cells. Once the area has been described, the planner can select subsets of cells that meet any number of conditions, such as having the value of specified attributes in given ranges and being adjacent to a particular kind of cell. New attributes can then be assigned to these subsets. Because attributes can represent such things as single-family housing construction and transit stations, the planner can propose changes to his analysis area, investigate the effects of these changes, and then accept or reject them. The planner is able to do this in an interactive computer-aided mode. In the first version of DISCOURSE, graphics provides just one of the aids available in the system: a "map" of the analysis area showing the values of a single attribute for each cell. Compared with normal planning practice, graphics is definitely downgraded in the system. The developer of DISCOURSE feels that this is justified, saying that "its graphics are intended only for the purpose of presentation—not analysis."

As a reaction to typical urban planning, which is often highly graphics-oriented, this approach to a system designed to improve the planning process appears to be warranted.

URBAN5—The purpose of this system (13) is to provide intimate communication between an urban designer and a machine, so that an evolutionary process can occur and so that the machine eventually will exhibit a kind of design intelligence, reflecting the methodology of a specific user. URBAN5 is therefore designed to study the artificial intelligence possibilities of a computer applied to urban problems. This highly experimental system allows the user to design within a three-dimensional rectilinear space and keep track of its own and user-supplied criteria such as maximum number of vertical surfaces in shadow and incompatibility of education and industrial spaces in the same location. Although the system was successful in providing a highly interactive system for the design of spaces, it was found to lack the generality necessary to be a true learning system.

URBAN COGO—This system (21) provides an urban information system based on such geometric objects as parcels, blocks, regions, and networks. Each of these objects, and a number of simpler ones, can be described with a user-generated set of attributes, such as number of buildings and number of families on a parcel. The graphical capabilities of the system include the following:

1. Graphical output capabilities, including both soft- and hard-copy displaying of objects or groups of objects with or without translation, rotation, or magnification, density mapping, selective mapping, and detailed mapping with full annotations; and
2. Graphical input capabilities by digitizing on a display screen or digitizing from hard copy on a flat-bed plotter digitizer.

URBAN COGO is designed to provide the base and direction for urban information systems of the future.

Santa Clara County Planning Department—In cooperation with IBM and the city of San Jose, the Santa Clara County Planning Department is developing a system of interactive computer programs for the prediction of the spatial distribution of households and commercial establishments (4). The system includes econometric, demographic, and location models that operate on a common data base. The graphical capabilities allow the user to display portions of the data base in a number of ways, including numerical listings on a CRT and analysis area maps with user-specified variables or operations on variables displayed for each analysis zone. When data are displayed numerically, they can be modified using the light pen and CRT keyboard. Development is continuing on additional submodels and expanded display capabilities.

The system is being used to study and evaluate the urban development policies of the local governments in Santa Clara County. This use is providing significant insight into the requirements for an interactive model system as a tool for regional planners.

Transportation Planning Studies

A pioneering use of CRT graphics was the "cartographatron" developed for the Chicago Area Transportation Study to display such transportation data as trip and locations and desire lines of area trips superimposed on an outline map of the Chicago metropolitan area. This device was operational as early as 1959 (3). In spite of this early beginning, computer graphics has played a relatively small part in transportation planning studies. Some use of the printer plotter mapping capabilities available in SYMAP exists (5). The paper plotter network displays available in the Bureau of Public Roads urban planning package of computer programs are used by a number of studies (26). Both of these applications are non-interactive. No cases of the use of interactive graphics by transportation studies are known.

Transportation Analysis Research

Although interactive graphics is not now being used in a production environment by transportation planners, research in this area has been very active in recent years.

In particular, the work done at the University of Washington, M.I.T., and the University of Illinois at Chicago Circle is of interest.

At the University of Washington, the Urban Systems Laboratory has been active in using an ARDS CRT console and a time-shared computer to develop three sets of capabilities: (a) a network manipulator that allows networks to be built and modified (18), (b) a network generator that seeks to find the "best" set of network changes (19), and (c) a prototype of an interactive transit system analysis package (12). Of the three, the latter appears to be the one most advanced from the prototypical stage to the production-oriented stage.

The M.I.T. Department of Civil Engineering has been experimenting with interactive graphics, as well as with ways to use a small computer with graphics capabilities as an engineering input-output station for the last 6 years. Before transportation application work was done, Foster (6) developed communications capabilities that allow the transfer of data between an IBM 1130 and an IBM 360. Stotland used these capabilities to send graphics information specified in 360 programs to an 1130 for plotting. At the 1130 end, the user can specify the plotting device but has little additional control of the picture produced (24). Silverstone and Mumford used Stotland's routines to produce network and desire-line displays generated in ICES TRANSET, a traffic assignment subsystem (23). Also, they experimented with the dynamic display of transportation data. For example, the speed on links of a network was displayed using dashed lines that "moved" from origin node to destination node at varying speeds.

Pradas-Aracil and Blumsack have developed a general system for the display of points and lines in one, two, or three dimensions (1, 16). This system allows files of n-dimensional points, and lines connecting them, to be read, edited, transformed, ordered, and stored for use in graphical outputs. Graphics can be drawn with a number of options, including specifying the dimensions of the axes, fitting of regression lines to points, and showing envelopes of maximum and minimum values. Although general in terms of the types of point and line graphs that can be obtained, this system does not include special features for such typical transportation graphics as network flow maps. The output device for which the system is designed is an ARDS CRT terminal with a keyboard for user input of information. Experimentation with this system has indicated that simple, only partially interactive systems can have sizable direct cost benefits.

At the University of Illinois at Chicago Circle (10), the Department of Systems Engineering has begun the development of a general computer system for the interactive analysis of planning and transportation problems. The development philosophy is similar to M.I.T.'s in that the emphasis is on a number of analysis models that operate on a common data base, as well as a package of graphical capabilities that can be used to display information from the data base. The initial version of the system has been named INTRANS (Interactive Transportation Analysis System). It currently includes, as one of a number of potential models, a subsystem for data analysis named BROWSE. This subsystem allows spatial variables to be displayed on a map of the study area and frequency and functional variables to be displayed in mathematical plots. Data base variables may also be transformed using mathematical operations. Future plans call for the addition of new subsystems to INTRANS, to include transportation analysis capabilities, to operate both on real data, such as zonal populations and commercial development, and on network data, such as multimodal transportation networks.

Summary

The use of graphics in the field of transportation can be summarized as follows:

1. There have been a variety of applications developed, production systems tend to be static rather than interactive, and those interactive systems that do exist have tended to be experimental in nature;
2. A great many of the applications are geographically based;
3. Experimentation on cost-effectiveness of the use of graphics in the transportation field has been encouraging (work at M.I.T. has indicated that even rather simple static systems can have cost benefits to the user); and

4. Some very useful first steps have been made, but a comprehensive interactive graphics system for transportation is still a long way off.

CONCLUSIONS

The underlying notion of our research has been to consider the relevance of interactive computer graphics in transportation analysis. The method chosen was a comprehensive look at trends in the field in general and existing operational systems both within and without the transportation field. Based on this work the following conclusions were reached.

From a direct cost viewpoint, interactive computer graphics has historically been uncompetitive, even though existing production systems demonstrate that man-time savings are easily achievable. This stemmed from the very high hardware and software costs present in the field. However, hardware costs are falling as are software costs (in fact, software now often exists for particular applications). At the same time man-time costs are rising. Therefore, it is expected that computer graphics will become more competitive in the future.

The intangible benefits of getting the job done better and more quickly must be considered in evaluating an interactive computer graphics system. This has historically been the case, in that existing production interactive graphics systems have been developed where the "product" was one of high value, due either to high costs (as in the aerospace industry) or to high volume (as in the automotive and oil industries). Because the product in transportation systems analysis is typically extremely high-valued and also very long-lived, the motivation for using techniques that will enhance the product clearly exists. An added incentive to the development of transportation computer graphics systems is the high social costs associated with "second-best" transportation systems, which are so closely meshed in our society.

A survey of proposed or prototype transportation graphics capabilities reveals that a substantial amount of work has been done in many aspects of the field. The potential for effective use of interactive computer graphics in transportation has been demonstrated. In addition, it does not appear that graphics capabilities need be fully interactive to be useful and cost-effective in all applications in the transportation field. Experimentation with the prototype M.I.T. transportation graphics indicates that simple, only partially interactive systems can have sizable direct cost benefits.

As indicated by the formula for direct cost savings, the amount of analysis time that lends itself to graphics applications is a critical variable in the determination of direct cost benefits. Existing industrial graphics systems have all been developed by very large firms with very large engineering staffs. It therefore becomes necessary at some point in time to approximate the potential use of a large-scale transportation graphics system. Initial thinking indicates that the system may require use by a substantial number of transportation analysts in order to have positive direct cost benefits. This argues for a coordinated approach to the development and use of an interactive graphics system by the transportation planning community.

In summary, the direct cost picture in interactive graphics is changing for the better, as hardware and software costs fall and man-time costs rise. The public climate is such that arguments for mechanisms for developing better transportation alternatives are likely to be heard. Substantial progress has been made by individual researchers in the field who have demonstrated that interactive graphics can be effective in transportation systems analysis. We feel that the time is ripe for the profession to take a coordinated cooperative look at the use of interactive graphics in transportation systems analysis, a look that will hopefully lead to useful modular interactive packages for the field at large.

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