Computer-Aided Design of Transportation Interface Facilities

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A prototype system for the preliminary design of transportation interface facilities is described. The design system exploits computer-aided design techniques including a microscopic computer simulation model and interactive capabilities to create an environment that enhances the transportation pedestrian facility design process. A summary of developments in transportation interface facility design, computer-aided design techniques, and user interface concepts is presented, followed by a discussion of a prototype facilities design system. Potential applications of the system are discussed, and promising areas of future development are outlined.

Transportation interface facilities are a critical element of the modern transportation system. Studies have documented the elasticity of transit pedestrian behavior with respect to station services, particularly with regard to the onerous nature of wait times (*1*). During the past two decades, significant progress has been made in the development of systematic procedures for the efficacious design of such facilities as well as specific objective techniques for the analysis of potential interface design layouts. Nevertheless, there remains a need for further development of design analysis techniques that specifically address the iterative, incremental nature of the design process.

In the following discussion, a computer-aided design environment for the analysis of preliminary transportation facility layouts is described. This design system takes advantage of techniques and computer tools that have been developed in other areas of engineering analysis; specifically, the system utilizes the capabilities of modern computer systems to perform complex microscopic simulations of pedestrian movement and provide an interactive design interface between the simulation model and the transportation professional.

PROBLEM STATEMENT

This paper is a status report of an ongoing research effort to develop a design system that exploits state-of-the-art computer-aided design techniques to perform preliminary geometry analyses of potential transportation interface facility layouts. The design system specifically addresses issues involving preliminary space allocation of a potential pedestrian facility design. This system exploits a high-performance computing environment in combination with a highly interactive user interface to enhance the preliminary facility design process.

The prototype design system features five integrated components (see Figure 1) linked to one another via a master driver program that implements user choices. The interrelatedness of the design system components provides an environment that seeks to improve the productivity of the facility design process by operating more harmoniously. To assist such a design process, the prototype design system features a highly responsive interface between the designer and the design system, which uses a variety of interactive hardware devices. In addition, the system offers the planner a variety of information display formats and design modification and analysis options in an attempt to incorporate user judgment and insight into the pedestrian facility design process.

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FACILITIES DESIGN PRACTICES

The design of a transportation interface facility is often considered first in architectural terms. Traditional architectural engineering design techniques may be used that treat a transportation station or terminal simply as a typical building design planning task. Specific issues that affect transportation pedestrian facilities are considered to be one part of a more broadly defined problem that includes land, buildings, building interiors, furniture, equipment, and machinery. This more generalized approach, referred to as facilities planning, offers the insights of an approach that does not specifically focus on the transportation aspect; in addition, the broader scope of this planning approach offers a glimpse into the advantages of a systematic integrated procedure for the design of a facility used by transportation patrons and other pedestrians.

The facilities planning approach defines building activity in terms of activities and departments, and attempts to accommodate interactivity flow patterns while anticipating present and future design constraints and expansion opportunities (*2, 3*). A variety of qualitative, and some quantitative, techniques may be used in each stage of this planning process. Of the analytical techniques available for the scientific and objective analysis of design alternatives, layout algorithms are most directly related to the transportation interface facility design problem (*3*). Developed over the past 25 years, these layout algorithms hypothesize the relative locations of key activities by using initial space requirement estimates in combination with matrices that indicate the degree to which activities are related. An example of such an algorithm uses a sequential operation to locate activities and departments based on the optimization of a computed distance coefficient, subject to prior constraints on the locations of key activities. Such facilities planning algorithms do not specifically focus on the pedestrian mobility issue, and hence do not generate layout geometries that necessarily accommodate realistic pedestrian flow. Because activity

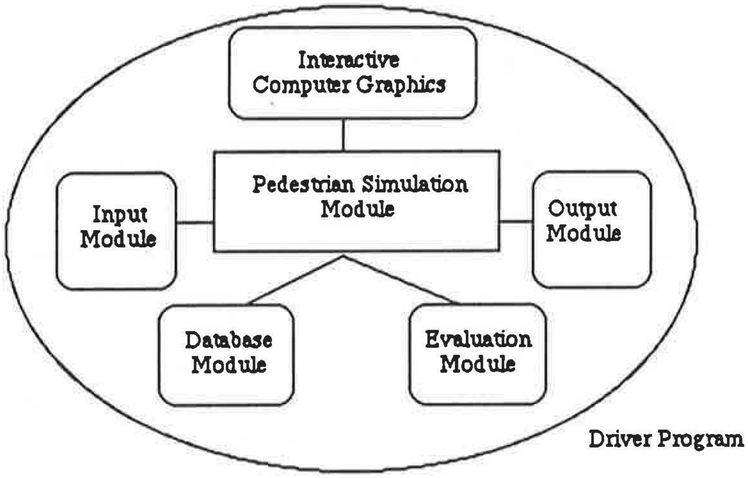

FIGURE 1 Prototype pedestrian facilities design system.

locations, rather than interactivity pathways, are of primary concern in such facility planning algorithms, this methodology, while illustrative of a comprehensive approach to building design, does not fully accommodate many of the important considerations that must be addressed by the transportation planner.

TRANSPORTATION INTERFACE FACILITY DESIGN PRACTICES

The challenge of effectively designing a transportation interface facility arises in part from the multiple functions that the facility must perform, as well as the often conflicting objectives that it must attempt to meet. Such a facility must accommodate not only the line-haul transportation system itself, but also the pedestrian ingress/egress process, pedestrian services, and facility operation as well. During the preliminary transportation facility design process, special interest is focused on the areas of passenger processing, transfer, and movement patterns (*1, 4*).

The multiple functions of a transportation interface facility affect the nature of the design process. A number of complementary and competing design principles have been developed that reflect the multidisciplinary engineering and transportation planning inputs that are required in such a design effort. Typical considerations for such a facility include (a) physical geometry of the facility, (b) information services for patrons, (c) service/processing facilities, (d) environmental considerations, (e) accommodations for movement-impaired patrons, (f) accommodations for present and future maintenance and growth, and (g) specific local programmatic considerations (*1*). The analytical techniques for these considerations vary greatly in sophistication and data requirements. For example, two of the most important considerations, physical geometries and service facilities, are often addressed through the use of general guidelines for maximum allowable dimensions of passageways and queuing areas. The utility of such guidelines is hampered by their nonspecific nature, a problem compounded by occasional overt contradictions between competing quantitative standards. Potentially useful information is also often unavailable or difficult to obtain because of corporate proprietary nondisclosure considerations.

The development of objective analytical techniques for the design of transportation interface facilities has generally not kept pace with analogous developments in other transportation planning areas. Studies in the mid-1970s concluded that only fundamental rules and guidelines were commonly used in the preliminary design and layout of transportation facilities (*1*); with notable exceptions, the body of work since then that addresses this issue has only occasionally focused on specific design techniques (*5, 9*). Techniques typically in use today generally fall into the category of deterministic analysis, including empirical studies and extrapolation to determine relationships between key design variables (*1, 6*). These techniques are marked by the use of aggregate measures of system performance to evaluate a process that is inherently time-dependent. Their shortcomings stem primarily from the difficulty in determining disaggregated design performance data, such as breakdowns by pedestrian mix and time of day, or uncertainties in pedestrian behavior. This shortcoming is understandable in light of the relative paucity of time-domain analysis tools. Other techniques have been developed that accommodate these characteristics; these probabilistic methods attempt to model the stochastic nature of pedestrian facility usage with variable success (*7*).

The most difficult, but potentially most useful approach involves the development of an integrated environment that attempts to model and evaluate the complex interactions of a design in a systematic fashion. One effort to systematize the categorization and design of interface facilities was conducted by Fruin in his classic description of pedestrian planning and design (*8*). Fruin described the inherent nature of a transportation interface facility as being a combination of building and structural considerations (including the physical plant); service considerations related to the mode of transportation being served; and human considerations involving actual and perceived congestion, waiting, and other psychological aspects of human movement. Another significant effort to systematize the station characterization and design process involved the delineation of several major categories and functions of transportation interface facilities. Hoel described these categories as (a) rail terminals with characteristic linear construction, with major emphasis on shelter and passenger service/transfer; (b) bus terminals whose construction is less constrained by virtue of the transportation mode they serve; (c) parking facilities that serve to ease congestion by diffusing the concentration of automobiles in central business districts and shifting them to peripheral garage locations; (d) transportation centers that serve multiple modes; and (e) multipurpose facilities that combine transportation with commercial and public amenities (*1*).

During the 1970s, significant progress was made toward systematizing the station design process, if only on a conceptual basis, in hopes that analytical tools, which would facilitate such a systematic approach, would be forthcoming. In one example of such a process, a procedure was outlined by Vuchic and Kikuchi, which, in many ways, mirrors the traditional transportation planning process. This process begins with an initial collection of station location and demand data, followed by data collection of external influences and conditions near the station. Studies are then conducted of projected alterations in land use and demand. On the basis of this information, the design requirements are specified along with guidelines for their implementation. Alternatives are formulated, and the best of the alternatives is evaluated (*9*). A second example was research conducted by Barton-Aschman and Peat, Marwick, Mitchell and Company, which envisioned a design procedure that emphasized station geometry and levels of service. Their procedure begins with a definition of constraints, followed by the collection of origin-destination data. Design objectives are then determined, after which a design is developed that meets objectives and constraints. This design is then compared with the design objectives to determine actual compatibility; an iterative process then commences, after which an optimal design is then reached. The structure of this approach implicitly assumes or requires the availability of a powerful and flexible analytical design evaluation tool (*10*).

Several prerequisites precede the successful implementation of procedures such as those described earlier. First, data requirements are imposing. Successful evaluation of alternative designs is predicated on the availability of accurate and detailed information on pedestrian traffic levels, the geometry and scheduling patterns of transportation modes being served, and, in the case of data collected from earlier design efforts, the prevailing conditions associated with those design projects. Other useful information includes the demographics or passenger mix of expected patrons, as well as the cost of passenger processing by transportation mode and service type. Even in the case of a computer-based analytical technique, where data requirements might appear to be less restrictive, some initial calibration information would be necessary for the generation of reasonable results. Second, human factors are often only peripherally considered in station design. Ideally, human factors considerations should go beyond standard design guidelines for ambient temperature, lighting, and noise absorption to also include psychological perceptions of congestion and overcrowding, which may affect space requirements and safety considerations. Fruin's contributions in this area are significant; nevertheless, more field data would be useful (*8*).

A third important aspect of the design process is the determination of objective criteria by which alternatives may be evaluated and competing choices compared. It is evident that the design of a facility in which complex human and man-machine interactions occur is fraught with complicated, often conflicting design objectives that vary from case to case. The problem of determining specific criteria is compounded by the difficulties involved in rational quantitative measurement of such criteria. In addition, those criteria that are quantifiable must be measured using the proper performance metric/indices. For example, the criterion of wait time may be measured in terms of mean time, maximum time, or some other measure; likewise, queue length may be measured by its maximum, average, or some other measure of length. Fourth, the evaluation process itself may be difficult to develop as well. Typical procedures include (a) cost-benefit analysis, which suffers from the requirement that performance measures must be converted into meaningful monetary values; (b) cost-effectiveness analysis, which becomes difficult to implement when many variables are involved (trade-offs become hard to resolve); and (c) ranking procedures, which typically employ user judgment to weight criteria. Finally research is needed in alternative design generation.

In the face of these imposing requirements, several researchers have addressed the challenges and potential advantages that could arise from the development of an integrated design system for transportation interface facilities. The most sophisticated analytical development of this type involved the construction of a computer-based pedestrian movement simulation model (*11–15*). Developed and tested throughout the 1970s by Barton-Aschman and Peat, Marwick, and Mitchell for the Urban Mass Transportation Administration (UMTA), this model, called USS (UMTA Station Simulation), was designed to be used as an evaluation tool for potential designs of intermodal transit facilities. Such a model would seek to identify capacity bottlenecks and areas of transient congestion to alleviate critical limitations at the early stages of preliminary facility design, thereby increasing the productivity of the design process and reducing design time and cost. The ambitiousness of this effort is rooted in its attempt to model the nondeterministic suboptimal behavior of pedestrians (*12, 16*); that is, develop a plausibly realistic model of actual human decision making. By using stochastic discrete-event digital simulation techniques, USS introduced a degree of randomness and uncertainty into pedestrian motion in order that critical time-varying aspects of pedestrian interaction could best be determined.

A program such as USS had potential implications for nearly every phase of the station design process (*11, 12*); nevertheless, despite, and because of, the complexity of the underlying model, USS is not currently in use. Its utility is constrained by difficulties of operation encountered by testers in actual use, as well as its implementation on limited circa-1975 computing resources. Nevertheless, in many ways USS represents a landmark effort to move beyond the handbook guideline and utilize sophisticated computer-based analytical techniques to model complex human interaction in transportation facilities, and thus offers direction, focus, and challenges for any subsequent efforts seeking to develop analytical tools to facilitate the systematic design of stations and terminals (*15*).

COMPUTER-AIDED TECHNOLOGY

Advances in computer hardware and software have reached a point at which a systematic approach to analytic engineering design is now within the reach of modern computing environments. The mechanical design realm has paid particular

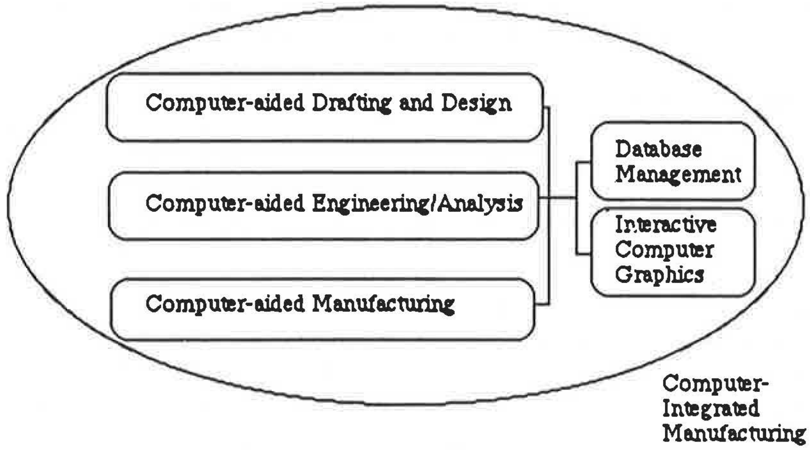

FIGURE 2 Computer-aided technology: mechanical design.

attention to the development of so-called computer-aided technologies such as computer-aided drafting and design, computer-aided engineering, and computer-aided manufacturing. Mechanical design systems are now addressing the issue of computer-integrated manufacturing (CIM), which attempts to unite each island of computer-aided technology into a unified, computerized whole. The computer-aided nature of these technologies arises not simply from the essential use of computers, but from the use of two key components: effective data base management and interactive computer graphics. It is these two components that make a computer-aided environment useful and productive (see Figure 2).

In the case of transportation facilities design, computer-aided technologies have been used in specific instances. For example, some interesting and potentially useful computer-aided engineering programs are available to perform analyses of potential station design layouts (*5*); in addition, computer-aided drafting programs are available for architectural plan generation. In general, however, the computer hardware advances of the past 10 years have not been fully brought to bear on the facilities design issue, even though there remain some potentially useful avenues for exploration. Two such areas of interest are the use of computer-based simulation models and the development of interactive user interface environments.

COMPUTER-BASED SIMULATION

One of the opportunities, and challenges, made available by the advent of the computer age is the development and utilization of computer simulations as an increasingly viable, readily available analytical tool for use by the transportation professional. Computer simulations are most often used when analytical closed-form techniques for the solution of a problem do not exist or are difficult to utilize; that is, when system complexity precludes a tractable formulation and solution. Simulations generally contain two key aspects. First, simulations are usually explicitly dynamic; that is, there is a time-dependent element. Second, simulation models are generally component-oriented. Rather than attempt to describe the system behavior as a whole, the system is modeled in terms of individual components, events, and interactions. Thus, more manageable submodels and local interrelationships can (presumably) be modeled, thereby allowing the resources of the computer to be concentrated on the assessment of the complex interactions and feedback between components of the system as a whole.

Computer simulations offer a number of significant advantages for the engineer-designer, particularly when compared with traditional alternatives such as physical "real-world" experimentation. These advantages include the following (*17*):

- Controlled experimentation. Under the control of the experimenter, the system may be exercised under a variety of deterministic or stochastic conditions. Relatively robust exercises of this type may be limited in a physical experiment because of fiscal or time limits.
- Time compression/expansion. An extended period of time may be simulated in much less than real time, thereby accelerating the analysis and enhancing cost-effectiveness. Likewise, transient phenomena, which may be difficult if not impossible to discern under normal, real-time conditions, may be simulated at slower than normal speeds.
- Sensitivity analysis. The susceptibility of the system to small changes in the values of variables or underlying assumptions may be assessed via manipulation of input parameters.
- Avoiding the real system. Experiments may be carried out without disturbing an existing on-line system or risking the practical and political difficulties that such tampering may entail.
- Training. Computer simulations are excellent training tools for the operation, analysis, and understanding of complex systems.
- Reduction of solution space. Computer simulations can facilitate early elimination of unpromising solution subsets as well as the detection of new, promising approaches that may not have been previously considered.
- Segregation of design validity from operational test considerations. A simulation is able to isolate the validity of the underlying logic of a system from the external and extraneous effects of test hardware that would accompany a physical experiment, thus avoiding the engineering testing analog of the Heisenberg uncertainty paradox.

Despite the attractiveness of these advantages, there are also significant disadvantages and hazards associated with the use of computer simulations:

- Cost. Simulation development and operation can still be an expensive proposition in terms of time, money, and manpower.
- Development uncertainties. Because the development of a proper model of physical reality for use in a simulation is so critical, the development time for an adequate simulation is often uncertain.
- Hidden critical assumptions. The inability to recognize and incorporate subtle interactions into the model may cause simulation results to diverge from reality.
- Initialization of the model. The complexity of the model may lead to substantial data collection requirements and potentially lengthy, even inconclusive model calibration in an effort to properly initialize the model.

Given these advantages and disadvantages, the typical procedure for the development of a simulation involves initial planning and feasibility of available resources, followed by the modeling and coding of salient system features. The coded model is verified for coding and other errors, and is then ready to be validated by testing and comparison with real results. The simulation is then ready to be utilized in an application. Simulation development, while converging on a desired solution, generally does not reach a steady state; the model is and should be subject to subsequent new information and increased resources (*6, 17*).

As an analytical tool, simulation requires the exercise of prudence and judgment in the proper development of the underlying model for a given situation. This requirement will always be of paramount importance. Given the appropriate development of such a model, however, computer simulations provide the means by which complex, otherwise intractable problems may be logically evaluated. Moreover, this tool is rapidly becoming readily accessible, as the growth of computer hardware and software capabilities and the drop in capital costs associated with their acquisition increases the availability of simulation capabilities for even a modest suburban or rural transportation planning operation.

USER INTERFACE DESIGN CONCEPTS

Despite the utility and implications of powerful modern computing systems, a nagging limitation has persisted, one that has afflicted even (or perhaps especially) the most sophisticated and complex programming effort, and that remains a bottleneck that inhibits the optimal interpretation of computer-generated information. This bottleneck involves the often frustrating restrictions placed on the user because of his or her inability to assess the often voluminous numerical output that is typically generated by computer-based tools. Only recently have computer users been provided the hardware and software necessary to obtain more useful information out of unprocessed raw data; nevertheless, computer output is still often in tabular form, making interpretation and assessment arduous.

A welcome development that goes a long way toward the alleviation of this difficulty is the rapid growth of the sophisticated user interface between human and machine. Almost inevitably, this is implemented through the use of advanced computer graphics hardware and software. The increasingly attractive price-performance ratio for computer power and computer graphics capabilities has encouraged the use of such tools to facilitate analysis, interpretation, and processing of computed and measured data (*18–21*). When used properly and exploited fully, a graphical user interface aids evaluation and decision-making processes based on a given data set by assisting the user in the maximum exploitation of the best of both human and computer information-processing capabilities. Moreover, such interfaces generally operate in an interactive environment, which can assist the human processes by providing the ability to pursue creative and intuitive possibilities (or even guesses) without the distractions and loss of concentration that would occur in a slower batch-oriented mode of computer utilization (*22*).

The advent of sophisticated computer graphics hardware and graphics software techniques offers singular advantages:

- Information transfer. The use of a computer graphics-based interface between the user and the computer program allows the utilization of human powers of assessment and assimilation to analyze multiple channels of information, thus facilitating the efficient and useful transfer of analytical information to the user.
- Design processes. By accelerating information transfer, a computer graphics-based interface allows more options of a design process to be evaluated in a fixed amount of time, or conversely, a given number of options to be evaluated in a shorter amount of time; the design time is made more productive.
- Data input correction verification. A visual representation of input data will often provide the user with the means to detect both gross and subtle errors of data input far more readily than with tabular output.

The usefulness of an interactive computing environment and computer graphics to increase the transfer of information to the user has been frequently asserted and almost universally accepted; in addition, research efforts have been conducted that lend scientific validity to that claim (*22*). Two theories have been put forth that attempt to explain, on a psychological, cognitive level the value of an interactive, graphical display of data. Cognitive theory states that an individual's information processing ability is compartmentalized into one of four elements of a two-by-two matrix of cognitive modes (*23*). On one axis, *information gathering* abilities are divided into preceptive and receptive modes (focus on general relationships and patterns versus focus on direct examination of detailed information), whereas on the other axis, *information evaluation* abilities are divided into systematic and intuitive modes (problem-solving via a step-by-step analytical process versus a heuristic, trial and error approach). Rinderle and Kornhauser note that those involved in decision making and alternatives analysis generally fall in the preceptive-intuitive mode, a mode that is difficult to articulate with regard to the precise decision-making process that is being followed, but for which it is theorized that the best assistance would be provided by a computer tool that allows rapid and interactive display of alternative data sets (computed and measured) in an iterative process.

In complexity theory, it is claimed that every individual reacts optimally, that is, maximizes his or her level of information processing, at a certain level of external information stimuli. For example, Miller's classic paper stated that a person is able to respond to and evaluate a maximum of approximately seven unrelated pieces of information at a time, and that the aggregation, or recoding, of raw information into groups of data improves useful information throughput to the user. Others have stated that not only the aggregation, but the format, influences information processing, and that graphical data present themselves in a form that requires little or no "post-processing" on the part of the individual. In short, information transfer is facilitated by the presentation of data in a form that minimizes the need for mental transformation.

The precise quantification of productivity gains as a result of an interactive design environment is elusive. Nevertheless, some studies and anecdotal evidence have strongly indicated significant gains in productivity as a result of a highly interactive user interface, especially when combined with interactive computer graphics. Studies have demonstrated quantitative improvements in productivity as measured by product quality and design cycle duration (*24*). In the case of engineering design, little doubt exists that interactive computer graphics offer greater insight into complex processes and interactions. Peitgen and Richter conclude that "computer graphics is enriching our perception to a degree rarely achieved by any tool in science. In graphical representation, natural processes can be comprehended in their full complexity by intuition" (*25*).

Examples of the use of an interactive graphics-oriented user interface to assess design alternatives include direct comparisons of the numerical attributes of alternative designs through multiple line or bar charts to demonstrate relative strengths of one design over another; such a comparison is performed far more easily and rapidly in graphical form than if the same comparison were made with two tabular data sets (*23*). The use of color-coding to determine critical areas of a network design may more quickly point out the relative advantages of one design over another than the tabular counterpart. Three-dimensional plots of one attribute as a function of two additional attributes help to assimilate multiple criteria relationships. The utility of such comparisons is enhanced when displayed in an interactive environment that facilitates rapid recompilation of revised data to obtain modified analytical results.

The importance of such productivity improvements lies not in their ability to fully supplant the design process, though recent developments in artificial intelligence and especially expert systems offer optimism in this regard. Rather, the significance of the interface between an analytical tool and its user depends on the ability of that interface to facilitate the design process by fully exploiting and merging the unique advantages of the computer in data and image processing with the uniquely human characteristics of data interpretation and image processing that are among the most difficult to model algorithmically in a computer program. The proper use of computer graphics encourages the combination of computer advantages in information processing, such as the retention of massive sets of detailed data and the rapid, consistent, and accurate performance of complex operations, with the human strengths of creativity, flexibility, and the ability to balance conflicting objectives, resolve ambiguity, and make judgments.

The remainder of this paper contains discussions on the capabilities of an interactive, graphics-oriented computing environment, dedicated graphics hardware, and highly interactive graphics to transfer multiple simultaneous channels of simulation-based data of pedestrian behavior to the planner.

PROTOTYPE DESIGN SYSTEM

Pedestrian Simulation

The pedestrian simulation model that forms the central core of the prototype design system follows the concept and inspiration of the simulation model utilized by the UMTA USS project (*14*). The key elements of that earlier effort have been retained, including the implementation of stochastic pedestrian entry to and exit from the system and stochastic queueing, as well as the inclusion of uncertainty into the pedestrian decision-making process, as manifested in the pedestrian path selection process. These stochastic aspects have been modeled in the prototype design system by using techniques developed for discrete-event Monte Carlo simulations. These techniques utilize a combination of pseudo-random number generator algorithms and hypothesized probability density functions to determine an appropriate mix and distribution of pedestrian entry and movement under uncertainty (*14, 26*). In addition to the stochastic modeling of pedestrian ingress/egress and path selection, the queueing process and pedestrian characteristics are stochastically determined as was the case for the USS model.

The selection of a probabilistic simulation approach was predicated on the need for a tool for the evaluation of potentially important time-varying phenomena that occur in pedestrian stations and terminals, thus providing a useful contrast and check for traditional aggregate time-averaged deterministic techniques and guidelines that are commonly used. This prototype simulation model is being designed as an evaluation tool, and addresses design objectives similar to that of USS:

1. Provide enough space in basic queueing areas to assure a safe, convenient, and comfortable pedestrian environment;
2. Provide enough service facilities to assure a convenient and comfortable pedestrian environment; and
3. Connect these areas to assure a secure, continuous, convenient, coherent, and safe pedestrian environment based on acceptable levels of service (*1, 10*).

As with the USS model, this prototype pedestrian design simulation requires input information on station design, including an abstract network that represents expected primary pathways, as well as locations of nodes on that network that represent path-branching opportunities for the pedestrian or queueing areas (gates, turnstiles, and the like). In addition, the user provides information on approximate pedestrian flow levels and general commuting patterns. This prototype model implements an important recommendation made with regard to future USS extensions; namely, that users be allowed to specify parameters such as pedestrian mix, stochastic distributions, specific subregions of interest, data output formats, and design alterations in a relatively painless and easy way. This is accomplished via a graphically oriented user interface that drives the iterative design process of this prototype system (see Figure 3).

Hardware

The prototype pedestrian facility design system utilizes the hardware capabilities of a Digital Equipment Corporation PDP

11/44 minicomputer as a host for the simulation model and other program components. This system offers 1.5 megabytes of main memory for programming applications. The other hardware component of this system is an Evans and Sutherland PS300 interactive computer graphics display system. This component features a high-resolution monochrome vector graphics display and programmable keyboard, along with a graphics tablet and control dials unit. The PS300 is controlled via a local graphics processor dedicated to graphics manipulation tasks and featuring a high-speed pipeline computing architecture. The two components complement each other by combining the general computing and storage capabilities of the host computer with the highly interactive, programmable environment of the PS300; moreover, the availability of a data transfer library allows this interactive environment to encompass both computing components at the same time, rather than operating each component in isolation (27) (see Figure 4).

This complementary environment is enhanced by the conceptual design of the PS300. The availability of local intelligence within the PS300 display system allows the segmentation of computations into graphical and nongraphical tasks, thus allowing the computing environment that is best able to handle each type of task to perform the required operations. In this case, the PS300 performs graphical manipulation calculations efficiently, while the host computer performs general calculations. The PS300's local power manifests itself in real-time, three-dimensional image manipulation and animation capabilities, a feature that is only now beginning to become available in affordable computer display systems (27).

Because programming tasks are distributed among two different hardware components, different programming methodologies are required. In the case of the host PDP computer, the simulation was programmed using a high-level language. Although such a simulation could be developed with any number of specialized languages (*17*), the availability of data transfer routines dictated that a FORTRAN-based simulation model would best serve the interactive goals of this prototype system. The PS300 may be programmed using its own programming and command language. Because tasks for the PS300 are graphically oriented and often involve the use of interactive devices, the PS300 command language is specifically designed to accommodate such operations. Using a data flow programming structure rather than the sequential von-Neumann schema of typical high-level programming languages, programming of interactive devices and linkages between a driver program and a graphics image are performed by using a concatenation of basic command language functions to form a so-called function network. This network analogy may be expanded to form a parallel network of interactive devices operating and interacting simultaneously, rather than in series.

User Interface

Following the initial development of USS, an evaluation was conducted to determine its usefulness and to suggest future improvements. The evaluation team concluded that the analysis tool was a potentially valuable adjunct to the station design process, but suggested that its usefulness could be significantly

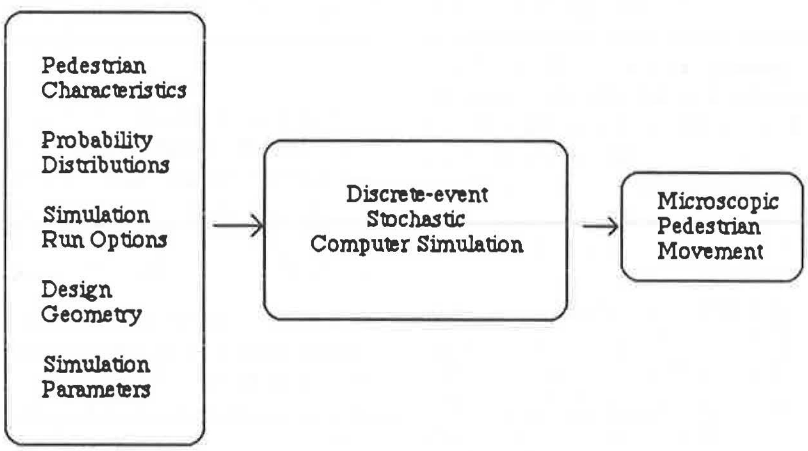

FIGURE 3 Pedestrian simulation flow.

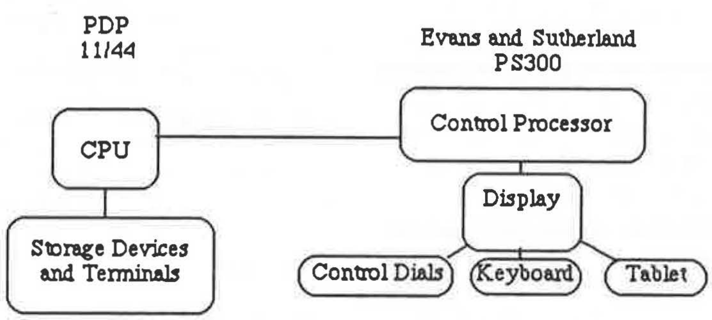

FIGURE 4 Prototype design system hardware.

improved. Among the recommendations was a suggestion that the implementation of an interactive mode of operation, as opposed to the batch mode that was used, would ease the difficulties of operation. In addition, the appropriate use of computer graphics to display input and output data would enhance the clarity of the simulation results. On the basis of these considerations, the prototype pedestrian facilities design system emphasizes a mode of operation that exploits an interactive design environment with a number of user-manipulable hardware input devices, as well as the extensive use of interactive computer graphics-based displays of input and output data.

The current version of the prototype design system implements three of the five components mentioned in the original problem statement (ongoing research is being conducted to implement the remaining modules). These components are the simulation module, the graphical output module, and some aspects of the input module. In addition, an interactive driver program has been developed to act as a shell that straddles the simulation and the output components. This driver program features menu-driven displays on both the PS300 and the PDP and provides the user with the ability to interactively display subsets of the output data, select the format of data display, modify the simulation input data and recompute the results, and compare competing design alternatives.

At present, the prototype system features four methods of interaction. The primary display features a graphically oriented menu on the PS300 that provides all the major design and display choices, including data selection, data display format, simulation input data modification, and simulation recomputation. Menu choices are made using a data tablet and stylus; selection of one of these choices results in the optional display of secondary textual menus that appear on a PDP display. Control of the program may be switched between the host computer and the graphics terminal by using interactive callable data transfer routines. Data displays may be manipulated by the use of other interactive devices. The control dials may be used for input of continuous, smoothly changing values; current implementation allows the dials to control the scrolling of text within a window, scale changes in two-dimensional plots, and three-dimensional manipulation of animated displays. Function keys may be used as toggle switches to interrupt dynamic displays and allow further inspection. These interactive devices are being used in an effort to enhance ease of use and facilitate the design process (see Figure 5). Data may be displayed in two- and three-dimensional forms ranging from line plots to bar charts, animated displays, and textual presentations. The development of these interactive display capabilities is based in part on earlier computer-aided ship design research (*29, 30*).

Current computer graphics hardware provides capabilities that go far beyond static two-dimensional plots and bar graphs. The current implementation of the prototype design system illustrates several of these extended features in anticipation of the availability of such hardware features at a more affordable level in the near future. The first extension adds dynamic display capabilities to two-dimensional plots and bar charts. A second feature that has been developed is a dynamic animation display that illustrates the macroscopic behavior of pedestrians in a design layout. A third feature exploits the ability of the PS300 to generate and manipulate three-dimensional wireframe images by providing the potential for three-dimensional modeling of animated displays. The animated display is currently two-dimensional; three-dimensionality may be implemented to allow the modeling of multiple floors, stairs,

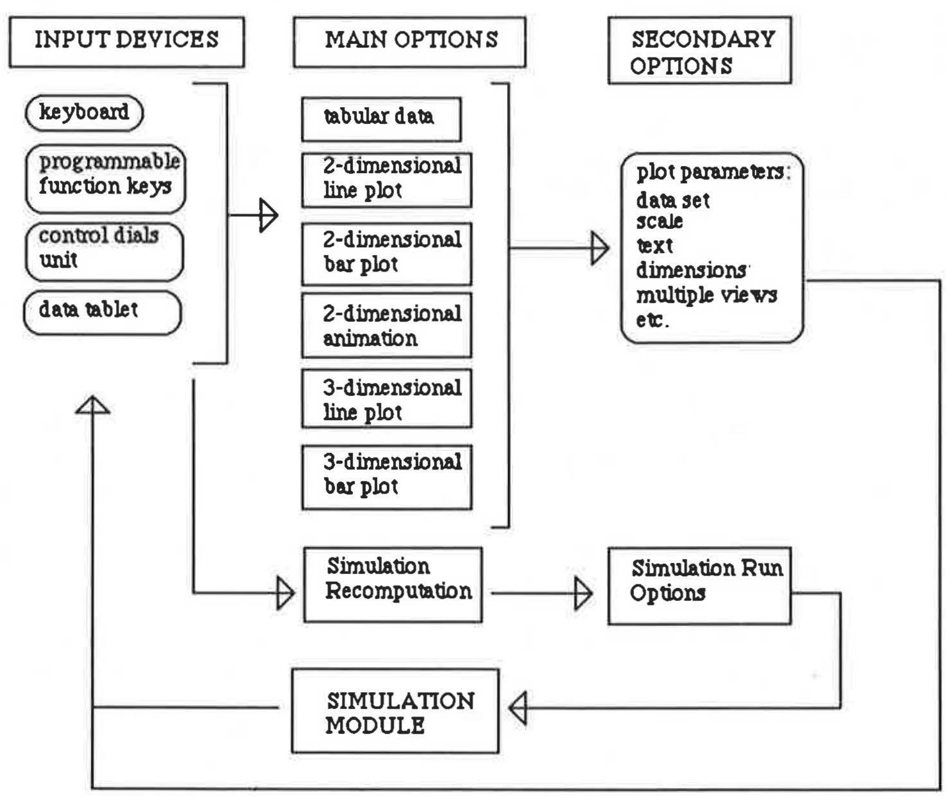

FIGURE 5 Prototype design system options.

elevators, escalators, and ramped areas. Finally, these capabilities are further tied together by the use of multiple tiled windows to allow the simultaneous, synchronized display of different but related data values. An example of this is the generation of an animated display, a two-dimensional congestion index plot, and a two-dimensional bar chart showing current pedestrian counts by link, with all the displays being shown together and dynamically updated and coordinated by the same clocking operation.

Design Process

An emphasis of this research effort is the natural incorporation of the simulation tool into the design process. This is accomplished via the use of a decision-making environment featuring interactive devices, as well as the utilization of dynamic computer graphics to further speed up the information transfer process. The nature of this new interactive design environment in many ways resembles the engineering design process often described in computer-aided mechanical design (*31*). The essential components of this design cycle include two features that may be exploited by computer-aided technologies: conceptual design and engineering analysis/evaluation. These two components are part of an iterative loop that ideally converges on the desired solution. The iterative nature of this process is a common part of this and most other design processes; yet, many analytic tools do not lend themselves to that feature. The mechanical design world has addressed this issue with the development of so-called synthesis models, computer programs that encompass design, analysis, and synthesis in an integrated structure. Its utility has been recognized in marine and aeronautical design applications; the prototype design system described in this paper seeks to implement the concept of a synthesis model by embedding the simulation analysis component within a design environment that facilitates and encourages iterative design and decision making on the part of the planner/designer. Current research efforts are focusing on an even more tightly coupled design, analysis, and synthesis structure in succeeding versions of the pedestrian design system.

The success of a design process that fully incorporates the iterative nature of the design cycle depends in large part on the ease with which the designer can compare competing alternatives. In the transportation planning and design process, decision makers are frequently confronted with the task of evaluating alternative, competing plans of action to address the problem at hand. The efficiency and comprehensiveness with which this task is accomplished has a critical bearing on the ultimate success of the design process, and may influence future station users for many years to come. In general, the process of determining the relative desirability of one alternative design over another should ideally provide the decision maker with information on the impact of proposals, the trade-offs and forgone opportunities involved, and those areas in which further study is warranted. In the field of transportation, design evaluation has evolved from an emphasis in the 1960s on the quantification of relative design advantages to a broader perspective that examines qualitative impacts involving externalities such as air and noise pollution, as well as such questions as the social equity of resource distributions (*32*). In the case of preliminary pedestrian facilities design, special attention should be given to the relationships and trade-offs that involve the level of service of the proposed design as a function of critical physical characteristics of the design, such as physical dimensions, relative locations of station components, the quantity of station features (e.g., ticket booths and turnstiles), and the perturbation of station parameters and simulation model assumptions.

As the complexity of the design problem grows, the degree to which human manual techniques can be used to determine the relative desirability of one alternative design over another decreases. In particular, a large set of evaluation criteria, coupled with variations in the relative importance of one criterion versus another, eventually overwhelms the engineer/designer with a multitude of conflicting data. The introduction of computers into the design problem offers some relief from this dilemma in several key areas of the design process. First, the appropriate use of computers can assist in the generation, aggregation, filtering, and extraction of useful information from large otherwise unusable sets of raw data, thereby easing the task of interpretation on the part of the designer. Second, the computer can be used to assist in the development of new design alternatives by increasing the efficiency of information transfer from computer to user. Third, the computer can in some instances perform automated design improvement based on certain well-defined, though sometimes limited criteria of desirable design features. Fourth, the computer offers the potential for "mechanization" of previously manual design alternative evaluation processes through the use of straightforward computer programs as well as more sophisticated artificial intelligence techniques such as expert systems.

This prototype design system addresses the design process by the use of an interactive environment and interactive computer graphics. Nevertheless, the problem of evaluation is difficult to address via semiautomated computerized techniques. Although a number of algorithms exist for the systematic evaluation of design alternatives, particularly in the field of operations research, caution must be exercised so that an algorithm is not strained in an attempt to extend its utility beyond the scope of applicability for which it was originally intended. The multivariate nature of station design would make the prospect of a single all-encompassing evaluation scheme remote at best. The complexity of the problem requires a flexible approach to evaluation, one that allows the user to select a number of different evaluation techniques in an attempt to extract the salient comparison. The current prototype version provides several means of design alternative evaluation, including simple comparison tables that provide cardinal measures of the values of key parameters for each prospective design, as well as weighted multi-criteria evaluations that use weighting or scoring techniques to evaluate alternatives and provide ordinal measures of design alternative comparisons.

The inclusion of several evaluation techniques reflects the difficulties involved in the computerization of human judgmental processes and expertise. Yet, this approach is consistent with an emphasis on the use of computer tools to assist human judgment rather than generate the "best" real-world solution independently, and also recognizes that the station design process is intimately accompanied by a political component, particularly in the evaluation and alternative selection process, which does not lend itself to automation (*32*). An emphasis in the current phase of research is the development not of a single approach used to the exclusion of all others, but rather the establishment of a systematic framework by which useful trade-off and ranking information may be provided to decision makers. An area of future research that offers an intriguing solution to this challenge involves the use of expert systems, whereby the heuristic knowledge of design processes is encoded into a data base that may be queried by means of an intelligent "inference engine" that performs the tasks of logical reasoning.

PEDESTRIAN FACILITIES DESIGN SYSTEM: EXPECTED UTILITY

The use of computer-aided design and synthesis model concepts in the transportation interface facility design process offers several potential advantages. First, design productivity is enhanced by the immersion of an analytic design tool within an interactive environment that offers rapid response times. Second, the maximization of useful information transfer is facilitated by the use of interactive computer graphics to combine data into useful forms that minimize the need for human post-processing. Third, the synthesis model concept offers an environment that encourages the typically iterative engineering design process. Fourth, computer-aided design concepts systematize the analysis and evaluation process for preliminary station layout designs.

The utility of such a design tool may be extended beyond the preliminary design evaluation of station layouts. The evaluation process could conceivably be extended to include the robustness of the design in the case of unusual or catastrophic events (*33, 34*), as well as sensitivity of the design to alterations in the initial working assumptions of the project. In addition, the increased effectiveness of presentations that utilize data generated in an interactive, graphics-oriented environment has been documented in several studies (*35*). Finally, the modular approach to station analysis offers potential generic utility beyond the transportation interface facility to include other pedestrian areas such as malls and public spaces.

FUTURE DEVELOPMENTS

This research only begins to exploit the potential utility of a highly interactive user interface in the pedestrian facility design process. Further enhancements are essential in the pedestrian simulation; this includes a more sophisticated model of pedestrians behavior as well as extensive testing to validate the model results. The caveats of simulation modeling notwithstanding, simulation-based design systems offer the possibility of analysis into the dynamic characteristics of motion within a design, an aspect that captures the essence of a station design, but for which analytical tools are few and far between. Along those same lines, one of the most important improvements that could be implemented in this prototype system involves porting the system onto a workstation environment that offers a more tightly integrated computing and graphics system, further improving the speed and flexibility of user interaction with the analysis system. The user interface should also be extended to implement a more flexible icon/window/menu-based interface such as that implemented for operating systems on the Apple Macintosh and Xerox Star. In addition, the use of color to enhance information transfer should be addressed. Recent developments in computer hardware have given rise to so-called "superworkstations" offering phenomenal three-dimensional real-time graphics response with greater affordability than ever before. A notable example of such capabilities may be found in workstations such as the Silicon Graphics IRIS 3030 system. Such an environment offers for the first time a "workstation of sufficient power [that] matches the spatial and temporal features of reality" (*25*).

Expert systems offer great potential for the consolidation of human expertise and an expert's line of reasoning into a computerized design evaluation process. Several components of the evaluation process are potential candidates for improvement with the help of expert systems. First, an expert system may be used to accumulate a data base of expert guidelines, judgments, and rules of thumb, as well as relevant city and county municipal codes, which could then be used to dynamically evaluate design alternatives and flag illegal design components, areas of potential improvement, and the expert's assessment of the degree of improvement. An expert system could also be used to process and compare several design alternatives at once; the rule data base could include expert judgments on the degree to which a typical "in-the-field" architect or contractor could correct a given number of illegal components and rule out those designs that exceeded the maximum number of flagged elements beyond which the design is deemed to be beyond help or completely unacceptable by the experts.

Yet another use for expert systems in the design alternatives evaluation process includes the implementation of a data base that contains design standards on lines of sight, lighting, and the like. Used in conjunction with an admittedly highly sophisticated modeling program, the expert system could be used to evaluate competing designs on the basis of expert assessments of architectural, psychological, and aesthetic characteristics. Given the highly subjective nature of such responses, it may even be appropriate for experts to provide a personal segregated data base in order that they could provide computerized, albeit subjective, design critiques on-line. Expert systems offer the ability to evaluate design alternatives based on legal, technical, architectural, and perhaps even aesthetic criteria, while mimicking the process by which experts utilize years of experience to assess a problem; this is particularly useful in the case of complex design issues where closed-form, algorithmic solutions are not well developed.

CONCLUSION

A research effort, which describes the potential of computer-aided design methodologies in the development of transportation interface facilities, has been outlined in this paper. The research seeks to illustrate the potential advantages of an analysis system that is closely linked to, and that more directly accommodates, the design process. By improving comprehension of data as well as providing an interactive user environment, such a design system offers the potential for significant improvements in the transportation interface facility design process. These design features are becoming affordable as supermicrocomputer-based computer-aided design capabilities become available in a networked workstation environment. Indeed, one of the most important by-products of the growth in the microcomputer and computer graphics fields is the increasing accessibility of sophisticated tools for the practicing professional with an accompanying decline in the necessity for consideration of operating expense and initial capital outlays. Transportation professionals should remain keenly aware of the tremendous potential of micro- and supermicrocomputer technology and its utility in the transportation field, particularly as it attracts and makes more accessible sophisticated tools such as simulations to assist in the analysis of complex problems.

A report on the state of station design procedures included the observation that "... deeply embedded in the consciousness of transit riders ... is that unpleasant, unrewarding, unaesthetic experience of getting off one somber train and waiting on a dreary platform for another. Inadequate planning has made the transfer no fun. One sometimes wonders how transit and transportation planners could have been more successful in achieving total error" (*1*). It is hoped that this singularly unappealing description will no longer be accurate as the art and science of pedestrian facilities design continues to evolve into a more sophisticated, objective, and productive process.

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