SOME PROSPECTS FOR SIMULATING HUMAN BEHAVIOR IN HIGH-RISE BUILDING FIRES: A PILOT DEMONSTRATION

Fred I. Stahl, M.Arch.
Environmental Psychology Program
The City University of New York
33 West 42nd Street
New York, New York 10036

ABSTRACT

The development of adequate fire safety provisions for buildings is seen to depend upon a valid formulation of a total building fire system, in which human-behavioral and physical phenomena interact. In an effort to comprehend and model such a system, predict human responses in building fires, and assess the usefulness of safety code provisions, a simulation-modeling methodology was evaluated for the case of high-rise office buildings. The model investigated generates human movement decision making behavior under conditions of stress and uncertainty, and is based on the probabilistic Markov process. The internal validity of the present model is examined, by (a) assessing the extent to which variance in the dependent variable (safe egress from the danger zone) is accounted for by predictor variables measured during actual simulation runs, and (b) determining whether the model is capable of distinguishing between diverse spatial designs. Simulation runs were conducted for two different office arrangements, and there were five replications for each arrangement. It was found that (a) Depending on the configuration of predictor variables, up to 88% of the variance in the criterion could be accounted for, and that up to 93.3% of the actual results of simulation runs were predictable by knowledge of these predictors. (b) The present model was incapable of distinguishing between "open-office" versus "compartmentized" designs on the basis of occupants' final egress status, time spent by occupants in threat-invaded zones, or time required by evacuees to reach safety zones. Implications of the findings, and areas for further investigation, are explored.

1. INTRODUCTION

The utility of various life safety policies and building design regulations becomes suspect, once considered in light of the casual assumptions about emergency behavior upon which actual decisions are based. The development of adequate and useful safety provisions is seen to depend, therefore, upon a valid formulation of the building fire system, in which factors describing the threat, human responses, environmental structures and other contingencies continuously interact. Moreover, various experimental or quasi-experimental techniques involving field observations appear - at least at the present time - incapable of providing data sufficiently useful for developing either a valid model of the building fire system, or a predictive tool for designers and policy makers (note 7 and 9, for extensive reviews of the literature on human behavior in building fires).

The objective of the present study has therefore been to develop an alternative approach through which to comprehend and model the building fire system, predict human responses in building fires, and thereby evaluate the "life safety potential" of various building designs, and assess the usefulness of specific safety policies and code requirements. The current report proceeds with the presentation of a simulation methodology, reviews data derived from an illustrative experiment designed to assess the method's usefulness, and points to research tasks necessary for continued progress in this area.

Throughout the course of the project, emphasis has been placed upon the study of fires in high-rise office buildings. Several factors contribute to this emphasis, notably: (a) In recent years, many cities have experienced disasters or near-disasters resulting from fires in tall buildings. (b) There appears to be growing public resistance to the idea of tall buildings. (c) Tall buildings appear most likely to pose severe physical limitations to emergency egress. (d) Tall buildings are generally considered to pose certain limitations on the control and extinguishment of the fire-threat itself. The author wishes to stress, however, that the basic techniques discussed within the scope of the paper are expected to be applicable to a considerably wider range of building types and user groups.

2. APPLICATION OF SIMULATION-MODELING TECHNIQUES TO THE FIRE PROBLEM

2.1 Rationale

With prospects for testing hypotheses about emergency behavior through field experimentation in actual settings considerably dimmed, the exploration of simulation-modeling techniques emerges as a viable alternative approach. The long-range practical benefits of experimenting with simulation models are expected to derive from opportunities for evaluating safety policies and code provisions, and for examining the life safety potential of design alternatives while still on the drawing board.

In the short run, moreover, the heuristic utility of the technique must be carefully considered as well. In particular, treatment of the building fire problem through simulation methods (whether via machine, game, or combination modes) is expected to yield immediate benefits in terms of our evolving understanding of the total building fire system. Simulation studies in which such variables as flame and smoke migration, building design and spatial organization, and occupant preparedness (to name just a few) are experimentally manipulated shall elucidate interrelationships among the many complex factors inolved; continually demanding that researchers define their concepts and clarify their conceptualizations as explicitly as possible. The application of simulation-modeling techniques to the building fire problem carries the further potential, then, of displaying theoretical structures underlying the building fire system, as such structures are brought to the surface over time. The heuristic value of simulation methodologies has been considered at length (note, e.g., 6, 8, 11).

2.2 A testable model of human behavior in a tall-building fire

Several attempts by various investigators to simulate human movement behavior in spatial contexts, and under a variety of conditions, have appeared recently (e.g., 1, 4, 12, 14). Clearly, these studies have been enormously useful as research tools, identifying parameters, assumptions and special difficulties, and demonstrating the potential value of a variety of simulation strategies.

One somewhat flagrant problem, however, has been a reliance upon deterministic explanations of human choice behavior and spatial movement strategy construction. Deterministic approaches implicitly assume that within some tightly bounded system, responses to stimuli or events are completely predictable by the model at hand. Accordingly, any additional variables not identified by the researcher, nor included within his or her definition of the system, are not accommodated by the overall analytical scheme. When comparisons between real-world findings and data derived from simulation experiments yield wide discrepancies, it is never really clear whether the difficulty lies in the structural design of the model in question, or in the possibity that some combination of unidentified variables is operating to contribute a sizable proportion of the total variance.

By contrast, the behavioral model upon which the current simulation study is based is essentially a stochastic process, which permits only the prediction of some range of outcomes, given a particular stimulus environment. Such a probabilistic paradigm recognizes that, indeed, some variables may have been overlooked or even purposefully excluded from the model, and that in their place some element of "chance" shall operate systematically.

A model so developed as been suggested primarily as a point of departure for more intensive simulation research into the nature of the building fire system. As shall become evident from the data presented here, the model was designed to describe human movement behavior in response to life threatening stimuli, within the boundaries of a single floor in a high-rise office building. Within a hypothetical environment so bounded, the model simulates individual and group movement decision making in a spatial field which contains information about a fire-threat advancing in real-time, as well as potentially mal-adaptive responses to sudden interruptions in goal directed behavior (10).

Accordingly, the building fire system is thought to be approximated by a Markov process (note 2, 3). Transition of this stochastic process from state to state is believed to be directly analogous to incremental changes in the fire system as it proceeds through real-time. For example, the system at time t may be described in terms of specific locations of individuals, flame and smoke products, numbers of individuals clustered into various groups, and the range of movement alternatives from those locations (etc.). At time t+1, the system has advanced to the next state: people have relocated to new spatial positions, flames and smoke have advanced (or retreated, etc.), and so on. Incremental changes in state-defining parameters are assumed to occur probabilistically, on the basis of parameter values for the most recent state only.

The current simulation-model is outlined in FIGURE 1. Note that each iteration of the routine represents a single transition of the building fire system between any two points in time, t and t+1. Specific details outlining the model's actual structure may be obtained from the author.

3. AN EXPLORATORY INVESTIGATION OF THE MODEL'S VALIDITY: DESIGN

3.1 The issue of validity in simulation-modeling

Two forms of validity may be considered in the present context. Internal validity refers to the logical consistency of the model's structure. One would expected, for example, that an internally valid model is relatively free of contamination from the confounding effects of uncontrolled variables, those dealt with accounting for a very substantial proportion of the system's total variance.

In addition, external validity generally concerns the degree of verisimilitude demonstrated by the model. One would consider a simulation externally valid if it produced data highly similar to those obtained from the real-world, with significant consistency. Ordinarily, an investigation of external validity would presuppose either the availability of reliable historical data, or the facility to conduct on-going or ad-hoc experiments in the real-world, against which to compare simulation data and thereby evaluate its verisimilitude. But in the case of the building fire system, neither opportunity is likely to be afforded the simulation researcher.

Under such circumstances, an alternative approach to examining external validity is offered through a variation of Turing's test (13). Such a procedure would basically require that data from both simulation runs and real-world experiences be presented to a "panel of experts" (the sources of data concealed), and that the experts attempt to distinguish between them. If, in a significant number of trials, the experts are in fact unable to distinguish those data generated from the simulation, then (according to Turing) one might be justified in considering the model externally valid. In connection with the current problem, experts might include fire victims, fire fighters, building code officials and architects.

One means of conducting Turing's test focuses on the administration of questionnaires to chosen experts. These instruments would include various statements about occupant behavior in building fires, to include (a) statements culled from interviews and actual reports by fire victims, etc., and (b) statements contrived by the researcher, designed to reflect behavioral patterns of ficticious "victims" of simulated building fires. In developing the original objectives for the investigation, it was hoped that such a test could in fact be affected, and that an initial effort toward ascertaining the model's external validity could be made. As the modeling and simulation strategies evolved over the course of the study, however, it became quite obvious that an attempt to apply such methods as Turing's test would lie well outside the intended scope of work. This belief stems from the facts that, (a) simulation-based statements for inclusion in the test could be generated only after sufficient data from simulation experiments had actually been obtained and evaluated, and (b) the whole issue of external validity itself only becomes salient once the model's internal consistency has already been largely verified.

But, Turing's test aside, these requirements themselves suggest somewhat formidable tasks. In light of the project's intended scope, then, the specific purposes of the current paper are to present: (a) a detailed discussion of the methods actually utilized to generate data describing a simulated building fire system, (b) an analysis of such data relevant to a discussion of the model's internal validity, and (c) indications of research tasks immediately useful in connection with the refinement of techniques and concepts initiated here.

3.2 The simulation model

The process of generating simulation data first required that the component routines of the model - conceptually expressed as schematic configurations - be developed into lists of logically executable statements. Such a statement listing has several distinct purposes, including (a) as an operational program for use in manually run "machine" simulation experiments, (b) as detailed guidelines for developing computer programs necessary for running high-speed complex machine simulations, and (c) as a framework for running the model as a simulation-game.

For the present validation study, the data resulted from manually operated "Monte Carlo" simulation runs. These involved the use of a desk calculator and random number table for computing probability functions and executing probabilistic steps. The locations of fire and smoke products, and of the simulated occupants, as well as other characteristics of each were graphically recorded by means of a pencil-and-paper technique, in which a single illustration represents the state of the building fire system at a given point in time, t. The default value for simulated time was preset (arbitrarily) at 12 units. At that point, any occupant in the run which had neither successfully exited nor been consumed by fire or smoke, was considered to have been still alive, but "trapped" within the danger zone.

The issue of calibration has been largely omitted from the present, illustrative study. Accordingly, it is not possible to assess exactly how much "real-time" is being represented by a simulated discrete unit of simulated time; and by extension, it is difficult to reflect just how quickly events would in fact occur in a real fire (e.g. flame/smoke movement, viz. occupants' own rates of movement). Accordingly, one cannot say just how far into the threat period the simulation penetrates in the course of 12 units of time.

The "operations sequence" (statement listing) is organized into a series of subroutines designed to accommodate the steps comprising the model. The subroutines, therefore, perform a variety of complex tasks, including: (a) Initilizing the simulation run (i.e., probabilistically preseting the threat-mode to operate during the run, the number and initial locations of simulated occupants, as well as certain individual characteristics of the "occupants"); (b) Flame and smoke migration over time; (c) Environment evaluation, probabilistic "interruption" prompting and execution, movement probability adjustment, spatial relocation of occupants (movement), and move evaluation, for each simulated occupant in each unit of simulated time; and (d) Updating all data records at the completion of each discrete time unit. The detailed operations sequence is available from the author.

3.3 Several assumptions underlying the current procedure

In evaluating data generated by the model, the reader should keep the following assumptions and caveats in mind:

1. Injuries incurred by "occupants" may be physical, resulting from fallen structural materials (for instance), or psychological, either resulting in permanent immobility for the remainder of the simulated time period.

2. At the start of a simulation run (time = 0), fire may have already done extensive damage elsewhere in the building, weakening its structure and increasing the likelihood that an occupant's path of choice be blocked by fallen materials (etc.), or that he/she even be injured by such materials.

3. Occupants who work in the building have participated in evacuation drills, and are already familiar with egress routes.

4. Secondary and tertiary fire ignition points (and concommitant migration patterns) have not been incorporated into the current model.

5. The model generates a constant fire/smoke migration pattern, which ignores the action of such external forces as air currents or extinguishment efforts.

6. The model does not simulate "helping behaviors" by occupants who confront injured individuals (note, for instance, 5).

7. The model does not generate auditory stimuli (e.g. "crashing" sounds, screams, public address messages, and so on), nor does it simulate human responses to either verbal or sign cues.

3.4 The simulation and validation experiment

This section outlines the structure of the experiment, while the findings themselves are summarized in part 4, below. The objective of the validation study, as mentioned, was to generate the behavior of a simulated building fire system (viz. a single floor of a high-rise office building), and to evaluate this behavior in such a manner as to shed light on the internal validity of the simulation model with which we are presently concerned. The specific problems addressed by the experiment were to determine (a) the degree to which "occupants'" successful egress from the danger zone is predictable from knowledge of other variables accommodated within the model, and (b) whether the model is capable of distinguishing between building plans which differ in spatial design (a presumably valuable function). Concerning the later issue, it was hypothesized that more "occupants" would escape safely from open-plan (versus compartmentized) spatial layouts - since these are presumed to offer a greater number of movement alternatives at any point in time, and to provide fewer corners and other opportunities for trapping individuals. It was also hypothesized that occupants of the open-office arrangement (viz. compartmentized space inhabitants) would spend fewer time units in locations already occupied by combustion products. Moreover, it was expected that occupants having escaped safety will have done so in fewer time units in the case of the open-office design (again, since there were presumed to be fewer barriers to goal directed movement behavior).

Method: "Occupants'" goal directed movement behavior was recorded in each of two simulated environments (open-plan versus compartmentized), in which a radially expanding fire-threat was simulated. Each of the environments (note FIGURES 2 and 3) was based on the same fundamental arrangement, viz. area, shape, and location of safety-egress zones (i.e. fire stairs). The two layouts - each representing ordinary "office" functions - differed only in terms of spatial articulation: one utilizing a relatively barrier-free arrangement, the other a cluster of enclosed office areas.

The expanding fire threat progressed radially from a predetermined point in the spatial field, and equal number of distance units per time unit. The model treats the movement behavior of occupants and combustion products independently, each in conjuction with its own rate of spatial displacement (adjustable by the researcher). The present configuration of the model operates under the assumption that flame and smoke migration are both slower and considerably more predictable than the movement of people. Accordingly, (a) a distance increment for flame/smoke migration is only a small fraction the size of a person-movement distance unit, and (b) the threat-migration subroutine in the simulation operations sequence generates flame and smoke expansion in a simple radial pattern.

The threat-migration subroutine, moreover, permits the simulation experimenter an opportunity to simulate various contingencies, viz. differential expansion and contraction of the separate entities, or phenomena produced by different types of fires, air-handling systems, etc. In the simulation experiment discussed here, smoke was further assumed to expand three distance units to every one unit of flame migration, per unit time. These rates were held constant over all simulation runs, for each of the test environments.

Simulated occupants, and the initial locations of each within the spatial layout, were randomly selected prior to any actual simulation runs. It was felt that a sufficiently rich array of illustrative behaviors could be observed (considering the size of the environments) by including six "occupants" in each run. Individuals were sampled on the basis of "their" (a) occupant status (i.e., "regular occupants" presumed to be familiar with egress routes, or "visitors"), and (b) interruption tolerance level, a factor utilized by the model in processing an individual's response to any sudden interruptions to his/her goal directed behavior that may occur. Once six individuals were selected, and their initial locations randomly assigned, they remained constant across all runs conducted for each of the test environments. Accordingly, the only parameter to vary between test environments was spatial layout. By controlling for flame/smoke migration patterns, individual "occupant characteristics", and occupants' locations viz. the fire ignition point and safety zones at the start of the run, it was expected that variations in the number of occupants to exit safety from each environment could be attributed to differences in physical design.

Procedure: The actual simulation experiment was conducted in a straightforward manner, as follows: After occupant characteristics and locations, and the threat-migration mode were predetermined, five replications were conducted for each test environment. This resulted in 30 occupants having "experienced" each environment. Although only six unique combinations of occupant status and interruption tolerance level characterized these 30 individuals, the stochastic model generated a unique building fire experience for each. Each replication was conducted in accordance with "rules" prescribed by the operations sequence. Occupants' move probabilities were adjusted by means of simple numeric functions, and movement decisions were made on the basis of random numbers drawn from a table.

The probability that an occupant would be suddenly interrupted by an external stimulus or cognitive association at any point in time was arbitrarily preset (for want of empirical evidence) at p=.50. The model permits this value to be varied, enabling it to reflect findings from empirical studies, or any other objective. Four illustrative examples of movement interruptions were actually incorporated into the current experiment, including: (a) a fear reaction resulting in temporary immobility of the occupant, (b) recollection of some recent item, event, or stimulus, or other cognitive association, precipitating "back-tracking" behavior, (c) physical or mental disability resulting in an occupant's total immobility, and (d) a physical blockage of an egress route, causing the occupant to re-evaluate alternative move possibilities. In the current experiment, each of these interruption modes was assigned (again, arbitrarily) an occurrence probability of p=.25. Again, it should be noted that these values can be manipulated by the experimenter (or designer) to reflect either empirical evidence which may become available, or special research or design objectives. In the present study, selected p-values are intended to be illustrative, and somewhat reflective of the lack of useful field data at the present time. Copies of simulated-occupant movement records resulting from typical runs may be obtained from the author.

Finally, a simulated-occupant was considered to have been consumed by fire (burned to death) or smoke (asphixiated) if s(he) (a) remained in a threat-occupied zone for more than three consecutive time units, (b) remained in a zone completely saturated by flame and smoke, for at least one time unit, or (c) entered into a completely saturated zone.

4. FINDINGS AND DISCUSSION

4.1 Predicting successful egress from the danger zone

It was expected that the parameters manipulated within the model would account for a substantial proportion of the variance in the dependent measure: the final status of simulated occupants. TABLE 1 displays means generated by five simulation runs for each of two environments. Data was provided by the model in the following categories: (a) occupants' final status, i.e. safely-exited, trapped within, or consumed; (b) occupants' original locations viz. egress zones; (c) occupants' original locations viz. the flame/smoke ignition point; (d) occupants' interruption tolerance levels; (e) total number of interruptions experienced by occupants in relation to their total numbers of active time units during a run; and (f) the total numbers of time units occupants spent in threat-occupied zones.

Matrices of correlations among these variables are provided in TABLE 2, for each of the experimental environments. Several intuitive expectations have been born out by these findings. The correlation coefficients reported here are for the compartmentized and open-office designs, respectively. For example, occupants located closer to egress zones at the time of threat ignition tended to escape more often than individuals located at greater distances from these zones ($r=-.54, -.43$; $p=.05$). Moreover, occupants located at greater distances from the ignition point tend to escape more often than those more closely situated, at the start of a simulation run ($r=.49, .36$; $p=.05$). In addition, it was found that occupants who evacuated the danger area spent relatively few time units in threat-occupied zones ($r=-.77, -.84$; $p=.01$).

Multiple regression analyses were conducted to assess the extent to which the criterion (whether or not a simulated occupant exited safely) could be predicted from knowledge of other parameters. The findings are summarized below:

Compartmentized office layout: It was found that knowledge of predictors (b)-(d) and (f) above accounted for 64% of the variance in the criterion ($R=.80$). In the instance where all five predictors were utilized, it was found that $R=.84$, with some 71% of the variance accounted for. The increase in R is significant at the .05 level ($F=4.89$, $df=1,24$).

In the case of an actual project in fire safety planning, however, a designer may only have approximations of parameters (b) and (c) viz. the hypothetical locations of work stations in relation to fire stairs, and estimations of potential ignition points. Even knowledge of these two variables yielded $R=.54$ (although only 29% of the variance is accounted for.

All R values reported above are significant at the .01 level. Where all five predictors are utilized, the following multiple regression equation was derived:

$$X'a=.40Xb+1.08Xc-.09Xd-2.00Xe-.71Xf+2.22$$

Open-office layout: In this instance, knowledge of all five predictors accounted for 88% of the variance in final occupant status ($R=.94$). This was significantly greater than predictions on the basis of measures (b)-(d) and (f) ($R=.88$, $F=19.96$, $df=1,24$), or (b), (c) and (f), ($R=.87$, $F=10.16$, $df=2,24$). These R values and F ratios are all signficant beyond the .01 level.

Using the locational parameters (b) and (c), estimates of which might be derivable by architects, a great deal more error is introduced, as only 21% of the total variance in the criterion is accounted for ($R=.46$, $p=.05$). The following equation was constructed on the basis of all five predictors:

$$X'a=-1.21Xb-2.84Xc-.70Xd-2.00Xe-.97Xf+15.39$$

4.2 Detecting differences between layouts

The suggestion that simulation modeling techniques would be useful in evaluating alternative building designs, on the basis of their relative life safety potential, has been implied throughout the paper. Such applications, however, presuppose that a simulation model (of demonstrated external validity) is in fact capable of distinguishing good from poor building performance. The capabilities of the present model were examined in the illustrative simulation experiment discussed here. The principal issues addressed involve (a) the final status of occupants, (b) the amount of time spent in threat-invaded spatial zones, and (c) the amount of time required by evacuees to reach safety zones.

Final status of occupants: It was hypothesized that more open-office occupants would escape the danger area (and fewer would be consumed) than would occupants of the compartmentized layout. Such an expectation seemed logical, since the open-office design permitted more direct egress routes, more move alternatives, and fewer barriers behind which occupants could become trapped.

A chi-square contingency table was analyzed to evaluate whether simulated occupants' final status at the conclusion of 12 time units was dependent upon the type of design inhabited. The frequencies are given in TABLE 3. The data indicate that final status was not contingent upon design type: chi-square=.09, $df=2$, n.s.

Time spent in threat-invaded spatial zones: On the basis of hypothetical advantages of open-office designs offered above, it was also expected that occupants of these arrangements would spend fewer time units spatially adjacent to flames, or immersed within smoke, than their compartmentized office counterparts. The mean number of such time units experienced by 30 simulated open-office occupants was 2.40 (s=1.69), while that for 30 compartmentized office occupants was 2.00 (s=1.86).

A t-test yielded -0.872, df=58, n.s. Accordingly, the null hypothesis that there is no difference between occupants of the two designs, was accepted.

Time required by evacuees to reach safety zones: The comparatively barrier-free environment of the open-office spaces was expected (again, hypothetically) to enable evacuees to reach safety zones (i.e. fire stairs) more quickly than evacuees from the compartmented office plan. The mean number of simulated time units required by nine open-office evacuees was 5.70 (s=3.29), as compared with the mean required for ten compartmentized space evacuees, 6.40 (s=3.77).

However, analysis of the data yielded: t=0.405, df=17, n.s. Therefore, the null hypothesis that evacuees from open-space arrangements do not differ from their compartmentized counterparts, was accepted.

4.3 Final remarks

It was found that variations in parameters measured during simulation runs accounted for a rather substantial proportion of the total variance in simulated occupants' final egress status, for each of the design types studied. Consequently, it would appear that other factors not incorporated within the framework of the model are of relatively little importance in predicting behavior in such a simulated building fire system (its external validity notwithstanding). These might include such variables as occupants' anxiety and fear thresholds, predispositions toward stopping to assist injured persons, ability to withstand certain thought-impairing effects of noxious smoke, and so on.

To some extent, the only predictor variables that the architect could be expected to predetermine (or certainly estimate) on the drawing board would be those relating to locations of individuals in the plan, with respect to the locations of proposed work stations, as well as exits, and in connection with the possible location of threat ignition points and migration opportunities (viz. HVAC outlet locations, partition ratings, equipment installations, etc.). The other predictors appear to be those either associated with individual occupant traits, or with individual experiences in a fire situation. Regarding the former, the architect desiring to employ such a model in the evaluation of building designs may be able to apply workable estimates. It may be possible, for example, to develop frequency distributions of relevant traits, for various building occupancy categories, in various locales, and so on. Indeed, a major objective of research in fire system simulation methods must be the identification of predictor variables which the designer can estimate at the drawing board, and which - at the same time - account for a substantial proportion of the variance in the egress criterion.

The present model is unable to distinguish between two seemingly disparate environmental conditions. Unfortunately, findings which fail to reject null hypotheses are difficult to explain, and shed little light on the question of the model's internal validity. For example, perhaps the hypotheses themselves were incorrect or illogically formulated; perhaps there is in fact little justifacation for expecting open-office arrangements to be superior to others. After all, while the open-plan office designs offer fewer barriers to safe occupant egress, isn't it also possible that the expanding threat - also unimpeded by physical barriers - is counteracting any advantage held by escaping occupants? Analysis of fire-victims' reports should illuminate this issue.

Or perhaps the internal structure of the model is incorrect - concerning its treatment of physical barriers. While it may recognize certain differences between the two designs studied, it may also be so insensitive as to require differences of unrealistically large magnitude. Again, empirical evidence would be useful in refining and sensitizing the model (notwithstanding the difficulties of collecting such evidence).

The difficulty with internal validation seems to lie with the issue of hypothesis selection in large measure, viz. the rationale for the researcher's interests, and their consistency with the model's capabilities. Indeed, the current hypotheses favoring the open-office design were accepted as purely speculative and illustrative, and not as having been clearly derived either from theory or empirical evidence. Accordingly, their value should be considered considered primarily in heuristic, rather than practical terms. The entire issue of distinguishing between alternative designs, however, is quite critical since the ability of a fire system simulation model to guide architects and others in the selection of favorable designs and policies - prior to a buildings construction and use - will be its primary strength.

Author's note: The research reported here was conducted under contract for the National Bureau of Standards, U.S. Department of Commerce, Order Number 512223.

Reference

1. BAER, A.E. A simulation model of multi-directional pedestrian movement within physically bounded environments. Carnegie-Mellon University, Institute of Physical Planning, Pittsburgh, Pa., Report #47, 1974.
2. HOWARD, R.A. Dynamic probabilistic systems, Vol. 2. New York: Wiley, 1971.
3. KEMENY, J.G. and SNELL, J. Mathematical models in the social sciences. Cambridge, Mass.: M.I.T. Press, 1972.
4. LOZAR, R.C. A methodology for the computer simulation of behavior-environment interactions in dining halls. In, Bazjanac, V. (ed.), Man-environment interactions: Part 10: Computers and Architecture. E.D.R.A. 5 Proceedings, 1974, 211-34.
5. MIDLARSKY, E. Aiding under stress: the effects of competence, dependency, visibility and fatalism. J. Personality, 39, 1, 132-49.
6. NEWELL, A. and SIMON, H.A. Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall, 1972.
7. PAULS, J. Fire safety and related man-environment studies. Unpubl. ms. presented at E.D.R.A. 6 Conference, Lawrence, Kansas, April, 1975.
8. RASER, J.R. Simulation and society. Boston: Allyn and Bacon, 1969.
9. RUBIN, A.I. and COHEN, A. Occupant behavior in building fires. Wash., D.C.: National Bureau of Standards, Technical Note #818, February, 1974.
10. SIMON, H.A. Motivational and emotional controls of cognition. Psych. Review, 1967, 74, 1, 29-39.
11. SIMON, H.A. The sciences of the artificial. Cambridge, Mass.: M.I.T. Press, 1969.
12. STUDER, R.G. and HOBSON, R.H. Simulation of human learning in urban movement systems. In, Preiser, W.F.E. (ed.), Environmental design research, Vol. 2. Stroudsburg, Pa.: Dowden, Hutchinson, and Ross, 1973.
13. TURING, A.M. Computing machinery and intelligence. Mind, 1950, 59, 236, 433-60.
14. WOLPERT, R.M. and ZILLMANN, D. The sequential expansion of a decision model in a spatial context. Environment and planning, 1969, 1, 91-104.

TABLE 1: Means for Five Simulation Runs, for Two Simulated Environments*

Run No.	Final Status[1]	Dist. to Goal[2]	Dist. from Ignition pt.[2]	Interruption tol. level	No. of inter's. per no. of moves	Total moves in a threat-occ'd. zone.
1	3.67 (4.00)	3.17	1.83	2.17	.41 (.59)	2.00 (1.67)
2	3.00 (2.00)	"	"	"	.57 (.82)	1.00 (2.33)
3	2.67 (3.00)	"	"	"	.60 (.37)	1.67 (2.50)
4	2.67 (1.67)	"	"	"	.60 (.54)	2.17 (3.33)
5	2.33 (3.00)	"	"	"	.31 (.51)	3.17 (2.17)
	2.87 (2.73)				.50 (.57)	2.00 (2.40)

Notes: (1) 1=consumed; 3=trapped; 5=escaped.
(2) distance measured in occupant movement units.

* Values in parentheses are for open-office plan; others are for compartmentized space.

TABLE 2: Correlation Matrix for Two Simulated Environments*

(N=30)	b	c	d	e	f
a. Final occ't status	-.54[2] (-.43[1])	.49[2] (.36[1])	-.26 (-.16)	-.15 (-.34)	-.77[2] (-.84[2])
b. Distance to goal		-.97[2] (-.97[2])	.72[2] (.70[2])	.03 (.02)	.45[1] (.66[2])
c. distance from ignition pt.			-.70[2] (-.69[2])	.00 (-.08)	-.37[1] (-.64[2])
d. interruption tolerance lev.				-.17 (.02)	.17 (.30)
e. no. interrupts./ total no. moves					-.13 (.09)
f. total moves in a threat occ'd zone					

Notes: (1) p less than .05; (2) p less than .01
* Coefficients in parentheses are for open-office design; others are for the compartmented design.

TABLE 3: Frequencies of Occupant Status Outcomes*

	consumed	trapped	escaped	
Compartmentized office design	12 (12.5)	8 (8)	10 (9.5)	30
Open-plan office design	13 (12.5)	8 (8)	9 (9.5)	30

X^2 = .09, with 2 d.f., N.S.

* values in parentheses are expected frequencies.

S. start
1. initialize the run
2. advance time
3. threat-move generator
4. look-ahead evaluator
5. interruption prompt
6. inter'n. generator
7. move prob. adjustor
8. move
9. move evaluator
10. consumed or escaped?
E. end

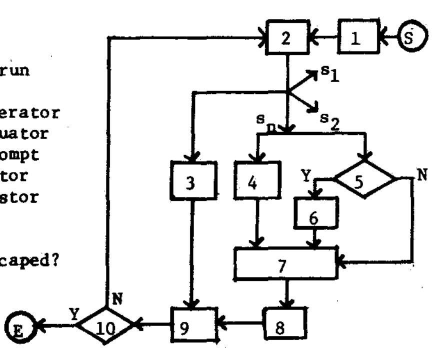

FIG. 1: OVERVIEW OF THE MODEL

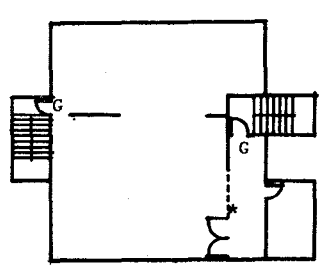

FIG. 2: "OPEN-OFFICE" PLAN

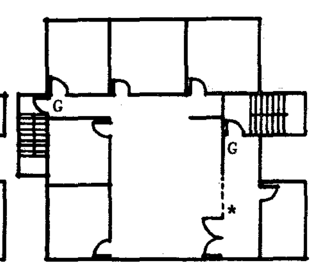

FIG. 3: "COMPARTMENTED" OFFICE PLAN

"G": escape goal; "*": glass partition