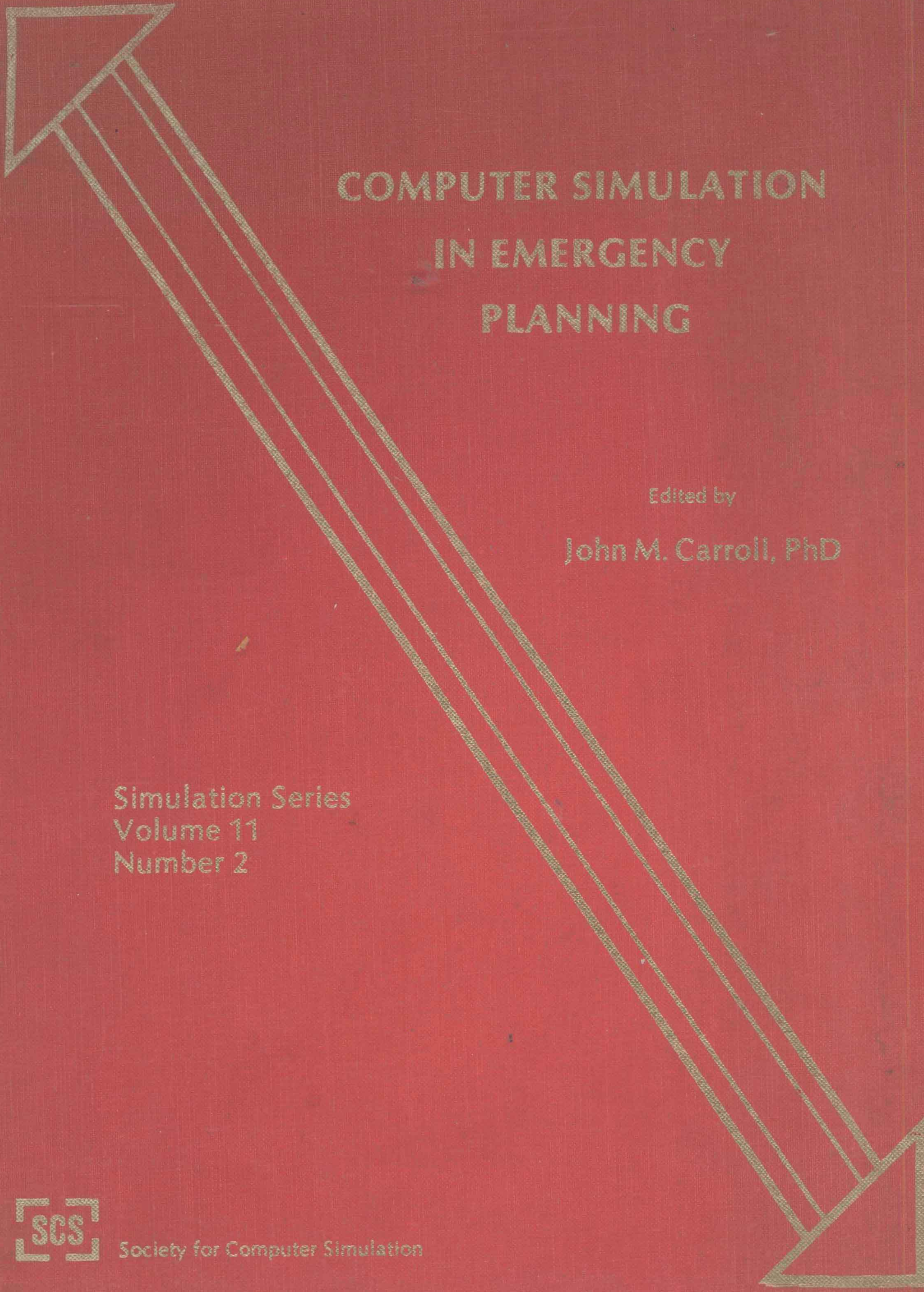

COMPUTER SIMULATION IN EMERGENCY PLANNING

Edited by

John M. Carroll, PhD

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PREFACE

There are as many definitions of what constitutes an emergency as there are emergency planners.

Some months ago, Dan Perley, General Chairman of the Conference on Computer Simulation in Emergency Planning, asked me about my activities in the field. I mentioned using simulation to optimize the location of fire halls, and to allocate resources for emergency hospital care. Dan characterized these as *routine* emergencies, then proceeded to tell me about the mind-boggling problems of coping with an uncontained nuclear yield.

Another time, I was on a computer security panel with a deputy fire chief of the city of Toronto when I characterized a catastrophic fire as one that destroyed all the computer-based records of a firm. "Not so," said the chief. "A catastrophic fire is one in which a person is killed." I couldn't argue with his point of view.

Actually, there is a continuum of emergencies ranging from anticipated perturbations of baseline activity, such as the "Saturday night fights" in a rowdy area of town, to those truly disastrous events in which destruction and mortality interact, escalate, and feed upon each other. These events can range from a fire all the way to the unthinkable nuclear holocaust.

In response to an emergency, there are four things that people can do:

Prevent it
Avoid it
Suppress its destructive attributes
Mitigate its undesirable consequences.

The papers herein cover all these approaches. Examples are: international crises management to prevent war, earthquake hazard assessment to guide land use planners, improvement of fire suppression equipment, allocation of resources for emergency hospital care, and assessment of potential earthquake damage based on land use.

A possible misnomer in the title of this volume is the word *planning*. Computer simulation covers a great deal more than planning. It also encompasses *training*.

Computer training simulators afford key people an opportunity to develop and perfect skills needed to avoid trouble or to control it if it occurs. In this volume, we examine the training of radiological health officers (who must cope with accidential release of radioactivity), managers of chemical oil spill containment, fire dispatchers, and operators and managers of nuclear power plants. Training simulators can allow emergency personnel to safely experience events such as the fire storms of a nuclear detonation. They also allow trainees to observe the results of their own decision making under simulated conditions of pressure. Senior administrative officials of lesser developed countries are among the users of this valuable tool for emergency service.

Planning is, of course, a central concern and it has at least three facets: development of detailed procedures, allocation of resources, and formulation of policy. This volume includes papers that address the formulation of policy in command and control, vessel entry into port, and even in what to do after a nuclear attack. We look at many aspects of emergency procedure developments aided by computer simulation, examining such diverse activities as crowd control, guarding nuclear facilities, and evacuating people from buildings and cities.

The final contribution of computer simulation to emergency service must necessarily be interactive decision support. One paper addresses this aspect in fighting forest and range fires.

All these applications of computers to emergency planning have in common a four-step process:

Acquire data
Model the problem
Computer scenario
Evaluate alternatives.

One paper suggests that neighborhood crime watch volunteers with personal computers could help acquire data in real time. There are many models: continuous, discrete, analog, digital, and hybrid.

In summary, the papers in this volume provide comprehensive coverage of a field that makes important contributions in today's world and promises even greater contributions in tomorrow's.

As a prelude to any of the papers in this volume, take a few minutes to read Ben Clymer's survey article, "Simulators for planning action against emergencies." Ben gets it all together for you.

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General

Simulators for planning action against emergencies

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ABSTRACT

A survey of the state of the art of dedicated simulators for use in planning is given for spills, fires, and structural failures.

It is concluded that a greater variety of dedicated simulators for planning action against spills, fires, structural failures, and compound emergencies are desirable and are within the state of the art practiced by the simulator industry.

INTRODUCTION

Simulators

A simulator designed to be a tool for training an operator in process control, as described, for example, in Refs. 1-7, is essentially the same as its ancestor, namely, a simulator for training a pilot in aircraft flight control (e.g., the "Link trainer"). Operator training simulators are concerned with reducing the incidence or consequences of emergencies by operator training.

An operator training simulator consists of the following functional parts:

1. A computer for simulating a process and any upsets caused by the instructor or naturally in the model.
2. An operator-simulator interface at which the operator can read process instruments and make manual adjustments to the process.
3. An instructor's station at which particular training runs can be commanded, operator performance can be monitored, and many upsets and malfunctions can be introduced.[2]

These parts are interconnected as shown in Figure 1.

The usual training runs include plant start-up, shutdown, normal operation at or near the design operating point, and some process upsets, equipment malfunctions or emergencies.

A simulator for planning action against emergencies is somewhat different from a training simulator:

1. The process model has many more adjustable parameters; very few are fixed.
2. The "trainee's station" becomes a workstation for introducing actions against an emergency and seeing the consequences.
3. The "instructor's station" is either absent or it becomes a workstation for the Principal Investigator.

Computer-based simulations and simulators are of two general categories: continuous and discrete. A "continuous" simulation deals with a set of algebraic and differential equations which are solved virtually continually, whether on analog or on digital hardware. A "discrete" simulation, on the other hand, represents a process in terms of discrete events.

Each type of simulation has its forte. Continuous simulation has been chosen most often for use in vehicle or process operator training simulators because most aspects of processes and controls are continuous.

The most widely known discrete simulations are those in which a simulation language such as GPSS or PASSIM has been used to write a program describing the behavior of a system whose elements and/or actions are discrete. Discrete simulation is the basis for the "procedural" class of simulator, in which the trainee essentially rehearses a sequence of actions specified in a standard procedure. Another class of discrete simulators has been developed for simulating disasters on the scale of a city and for simulating efforts to combat the disaster.[8]

Another type of simulator, which need not contain a computer, makes use of "physical simulation" in which a model and displays are incorporated into a physical system representing the system of interest. A simple example would be a scaled-down version of a river or a fire, using scaling laws to try to compensate for size differences. An alternative is to use an analogous but different physical system in a physical simulator.

Simulators can be classified also in terms of whether the operation is deterministic (in which case only one run need be made for a given situation) or stochastic (in which case one must run an ensemble of runs in order to develop statistically significant measures of means and variances). It is often desirable to take the stochastic approach, in order to have a sound basis for plans. The stochastic approach is necessary when uncontrolled boundary variables (such as wind speed in a fire simulation) are fluctuating and/or uncertain.

The word "simulator" is being used also (confusingly) to mean a software package which a programmer can use in writing a simulation program. Most simulators of this type have been developed for application to general process simulation. However, they could be applied to the simulation of emergencies. In this paper the word "simulator" will mean a system containing its own hardware, unless otherwise stated.

Simulators occupy a continuum of degree of dedication of the computer used:

1. At one extreme is a simulator incorporating a 100%-dedicated computer used much of the time for developing plans.
2. At the other extreme is a general-purpose computer used only occasionally for running a planning program, and lacking any more of a man-machine interface than a conventional terminal and printer.
3. In the middle is a continuum of possible facilities and usages.

Emergencies

Emergency "situations" of the simplest types can be considered to be boxes of a matrix of which the row headings are the "systems affected" and the column headings are the "phenomena" constituting the emergencies. A sample list of such situations is given in the first column of Table 1 (the rest of the Table is not of concern at this point).

Some categories of systems affected would be: a body of water, a vehicle, a process plant, an oil well (on land or offshore), a pipeline, an airshed, a building, and a tract of land.

The emergency phenomena would include a fire, a spill, a structural failure, an explosion, a flood, an earthquake and a nuclear detonation.

Simulators of Emergencies

There are many types of organizations which have a potential use for simulators of emergencies for various purposes. Examples are given in Table 2 for just the fire category of emergencies. Therefore, there is a motive for pursuing the idea of simulators for emergencies of all kinds, which is the aim of this paper.

There are at present few simulators of emergencies which, as such, are used for planning purposes. However, there are hundreds of process training simulators which can simulate anywhere from 10 to several hundred equipment failures, some of which are serious emergencies. For example, some "emergencies" on offshore platforms which would be included in a training simulator are:

a) loss of power
b) accumulation of combustible gas in underventilated areas
c) line rupture, causing hydrocarbon leak
d) fire
e) severe weather

There has been a strong trend to increasing concern with greater detail and realism in the simulation of those situations that are unlikely to arise in a process. The best known single incident which had this effect upon operator training simulators was the accident at Three Mile Island. In effect, process simulator designers have been making more extensive inroads into abnormal conditions of all types, including emergencies and disasters.

The new training objectives associated with this trend to training for emergencies are of two types: preventative and corrective. The objective of preventing emergencies requires training operators to be alert, to recognize incipient emergencies, to diagnose the problem, to understand the dynamics of the process and its controls under abnormal conditions, to make full use of available data, to maintain an appropriate emotional state, and to be able enough to process forecasting to give him an idea of the urgency of his situation. The objective of correcting emergencies requires a knowledge of the consequences of all available control actions, an ability to design a course of action on the fly, and courage to take action when it is needed.

To an extent it is possible to use some process training simulators for some planning purposes without change to the simulators. Planning can be even more feasible if appropriate modifications are made to the man-machine interface and the simulation software. However, in general training simulators have a limited inherent suitability to be converted into simulators of emergencies for planning purposes.

The planning of emergency prevention or response to an emergency can be conducted by means of simulations. The setting of the planning can range from immediate decisions at the scene for swift remedial action to long-range research studies leading to plans and policies on paper for future use.

Simulators of emergencies can be used not only for planning but also for training in planning.

SPILL SIMULATION

State Of The Art

Releases of chemicals, usually spills of liquids, can occur on any terrain or directly into water. Some of the more important parameters which characterize a terrain are surface porosity, surface shape (flat, slope, ditch, mound, swale, etc.), proximity of body of water, and nature of body of water (pond, stream, etc.). The spill itself can be characterized by a total volume spilled, viscosity, vapor pressure of saturated liquid, specific gravity and solubility in water.

A spill is not in itself an emergency, but a spill can create emergencies. However, if it contains radioactivity or a hazardous chemical, it can pose a threatening pollution of air and/or water. If it is combustible, it can be a fire or explosion threat. Therefore, training and planning for handling spills (containment by dams or floating barriers, diversion of flow, pumping to storage, absorption, etc.) is desirable.

Simulation of a spill can involve a variety of physical and chemical processes, including overland flow, mixing, stream flow, diffusion, evaporation, downwind dispersion, and movement of a liquid in a permeable solid.

A considerable body of work has been done in the development of simulations of spills and releases of substances which constitute or provoke emergencies.

Some examples of state of the art undertakings are as follows:

1. The U.S. Coast Guard has computer programs which simulate, on a continuous basis, a rapid release of a fluid (e.g., oil, ammonia, chlorine or other hazardous chemical) from a ship, and a procedure for following the spilled fluid pool into the midfield and far field distances on the surface.[9-13] Vapor dispersion is of particular interest, in order to track the flammable or toxic volume. Vulnerability of impacted population is evaluated.

2. The U.S. Nuclear Regulatory Commission has stimulated a rapid growth in the art of simulating emergencies in nuclear power plants, including the internal and external environment, for the sake of operator training. Some of the most serious emergencies would involve spills or releases.

3. The art of simulating plume formation, downwind transport, diffusion, chemical reactions, fallout of particulates, etc., for atmospheric pollution on a scale of tens or hundred of miles is well developed. These processes are involved in many emergencies to be simulated. A typical plume transport model is given in Reference 14.

4. Many simulations have been developed which could be used, directly or with minor alteration, to predict the dispersion of a pollutant in any body of water.[15]

5. The art of ecological system ("ecosystem") simulation is well established for showing dynamic responses and interactions of the living and nonliving environment when insulted by emergencies.[16,17]

6. Several companies are selling software for simulating episodic spills.[18]

Spill Simulators

The class of simulators of spills and releases of toxic or otherwise dangerous fluids is a new area of development in the simulator industry.

Esso Resources, Calgary, along with a consortium of oil companies and Environment Canada, let a contract to Computer Devices Canada (part of Control Data Corp.) to develop training simulations of two oil spill scenarios (oil slick with booms and skimmers on river or ocean) with interactive graphics and light pen for training of on-scene commanders.[19,20] The simulator was demonstrated in the summer of 1982. It gives some training benefits, and it points to further possibilities for features in spill simulators. The simulation is of the discrete type.

A discrete simulator of a large class of spills for purposes of research, training, and real time command and control has been under development at Goodwood Data Systems.[21]

A dedicated simulator for chemical spill and release emergency management was put on the market in 1982.[22-24] The user enters the source location with a light pen, and he enters wind data, local topography, and properties of the released substance with a keyboard. Then the size and position of the toxic cloud are predicted and displayed on a CRT diagram of the terrain generated by computer graphics. From this display the user can activate appropriate emergency management actions suggested by the simulator, such as phone calls (which can be automated) to notify emergency response teams and to warn occupants predicted to be at risk in the path of the toxic cloud. The simulation also provides predictions of vapor concentration at a specified downwind point of danger, the time of maximum concentration there, and the time when the concentration there will fall to safe levels.

Somewhat similar systems are being developed for use in nuclear power plants.[25]

Likewise, one could envision a simulator for predicting dispersion of a pollutant down a river having user-specified tributary and outfall locations, as well as flows and upstream mainstem flow, and predicting arrival time at a water purification plant intake downstream of the point of entry of the pollutant. Availability of some downstream concentration data would enable identification of the source magnitude as a pulse or steady flow rate by a regression procedure. A centralized simulator could deal with any of the streams in its region of responsibility, including an arbitrary temporary containment behind an emergency dam, or other overland flow to the stream.

FIRE SIMULATION

State Of The Art

The National Bureau of Standards has been doing some fire modeling research and has been developing improvements in continuous simulations of fires in a room, building, or aircraft cabin.[26,27]

Mathematical models of combustion thermochemistry, heat transfer, flames, gas convection, firefighting processes, weather effects, etc. are all available in various degrees of refinement. Parameter values are readily available to be changed by an instructor at the start of each training run. Such advanced computational methods as Lagrangian (moving frame) particle tracking techniques and finite Fourier series (assumed modes) techniques for solution of the partial differential equations are being investigated.[27]

Studies of fire stability in a building are being conducted at the National Research Council (Canada). The emphasis is upon understanding the dynamics of fire growth.[28] One of the most successful and elaborate codes for simulation of fire growth and spread in a building is being developed by Howard Emmons of Harvard University.[28,29]

In general, the state of the art of fire simulation is as described by Clarke of the National Bureau of Standards, Reference 27: "...we are learning to predict fire growth in an increasing variety of real situations; this prefigures the evolution of fire modeling into an engineering tool."

Deliberate controlled "fires" are at the heat of many process simulators, such as those containing a boiler, a gas-fired and/or oil-fired heater, a calciner or kiln, etc. Some process simulators contain a simulation of detection equipment and of the occurrence of a fire in the plant, but the training done is only in emergency shutdown, since the process operator ordinarily has no role in firefighting. The effects of such actions as injection of foam into the base of a tank to quench a hydrocarbon fire are not simulated.

In order to assess the severity of fires, one important ingredient of severity which must be evaluated is the loss of life and the severe burns resulting from a fire. The process of egress of persons and evacuation of buildings during a fire has been the object of many discrete system simulations akin to operations research, such as the several papers in Reference 30.

The foregoing art applies chiefly to indoor fires. There has been a lesser activity in development of simulations of fires in forests and other wildlands.[26,31,32] Moreover, the models of outdoor fires have tended to be simpler than models of building fires. Nevertheless, the accuracy of prediction is quite sufficient to permit faster-than-real-time simulation for planning how to fight a fire in progress. The main inputs are ground cover fuel value, wind speed and direction, and topography.

Fire Simulators

For the past 10 years there has been a creative ferment of independent developments of simulations which have been used for several kinds of fire and firefighting simulation for training. These developments will be described here as being on two levels: (1) direct fighting of a fire by one person; (2) the level of communication among, and command of, those who are fighting a fire as a crew.

A system on the individual firefighter training simulator level was developed about 10 years ago by the Ansul Company for its own use in training customers.[33] It had a 7x7 foot screen with load cells at the corners to measure the reactions to a gas stream (simulating a dry chemical extinguisher) played upon the front of it by the firefighter. A computer used these reactions to determine the instantaneous amount and direction of the stream. This information was used in a computer to determine the growth or decay of the fire. The varying fire state was then used to control a projection on the back of the screen of a moving picture and slides to portray the fire and scene. Also controlled were a set of shutters to alter the apparent intensity of the fire, the loudness of a sound track of fire noise, and the position of trapdoors to pass or intercept radiant heat from Calrod heaters beamed on the firefighter.

In the category of computer-driven physical simulators a noteworthy example is the fire simulator developed and marketed by Advanced Technology Systems.[34] It uses an actual propane gas flame to simulate the flames of many kinds of fire, which the student tries to extinguish. The types of fire which can be simulated include an airliner cabin, a tall building, a refinery, a residence, a store, etc. A computer controls the parameters of the flame according to the instantaneous state of the fire, as computed to be affected by firefighting efforts and environment. Several independent "fireplaces" in separate rooms can be controlled by the same computer, and the system is modular.

One can imagine an all-electronic simulator which would show the fire to the trainee on a color display and which would accept trainee inputs from a two-angle joystick (simulator of hose direction angles) having a stream on-off switch. Intervening between the joystick and CRT or projection TV display would be a computer-controlled system having such features as:

1. Colored pictures stored on videodisk for quick retrieval and display in a sequence called by the computer as needed.
2. Computer graphics to generate alphanumeric or other graphic symbols to superpose on a picture, a cartoon of a stream of water, smoke clouds, a firefighter as a stickfigure or more elaborate cartoon figure, and flames of specified location, color, size, shape, etc.
3. Computer simulation of the dynamic growth and spread of the fire, to drive the graphics.
4. Blanking out of background by any opaque intervening object.
5. Ability to modify the hose nozzle location under the trainee's control.
6. A light pen to call out use of an axe on a wall.

While not affording the neuromuscular and radiant heat experience of the physical simulators, the electronic simulator could be used to give training with a wide variety of fires, and it could be used in planning strategy and tactics.

The simulated urban firefighting command and communication problem involves discrete simulation and such decisions as allocation of firefighters, placement of fire engines, selection of hydrants and hose runs, use of special extinguishers, and so on, knowing from communications and a special display most of the desired information. This problem is very like a war game, which was an ancestor of the technique.

The state of the art of simulators for training in urban firefighting command is illustrated by the $300,000 facility of the National Fire Academy, Emmetsburg, Maryland.[35] It was installed in early 1982. Two trainees' rooms are served by one control room between them. Each of the classrooms has a 4x8 foot screen onto which 16mm slides of scenes are rear-projected from the control room. A classroom contains communications with headquarters, three firefighting units, and the instructor. The fire image is rear-projected by a color TV, using red for the fire and green for smoke. Between the light source and lens system the light passes through a transparent plastic endless moving belt, which is speckled with paint, in order to give the impression of movement of the flame and smoke. The whole operation is coordinated by an HP1000 microcomputer, which contains a selected scenario. The computer dictates which slide is to be shown, and it commands a subsidiary Atari computer to modify the smoke and flame images. Students' actions are not hands-on; they are converted to computer inputs by the instructor. In mid-1982 the system was being debugged. One of the difficulties is that the flame and smoke images from the TV are not as bright as the scene background brightness from the slide would dictate.

Another class of firefighting command and communications problems concerns outdoor fires on open or forested land. The art of computer simulation of such fires and their spread is developed well enough for many purposes.[31] Although there is apparently no application yet to training or planning simulators, it appears to be a natural future development. The present art for training uses experts behind the scenes to translate trainees' actions into consequences for the fire. The whole operation is like a precomputer age war game, with use of maps and poker chips marked to represent mobile resources.[32]

Development of new hybrid combinations of continuous and discrete simulation technologies in simulators having appropriate uses for both would be desirable: for example, a two-level simulator for crew training and procedure planning, using discrete simulation on the command level and continuous simulation on the operator level.

STRUCTURAL SIMULATION

State Of The Art

The art of simulating the dynamic behavior of all types of structures is long established. The most common digital code is NASTRAN, which was developed for NASA by MacNeal Schwendler Corp. The analog art is given in Reference 36.

Types of structures which are well understood in terms of simulation include vehicles, civil structures, pipelines, and process plants.

The forces and phenomena causing disastrous structural damage include earthquakes, corrosion, load resonance, flutter, collisions, snow, or explosions.

Post-failure behavior simulation of a structure is strongly nonlinear, but the principles are well known. Small-amplitude behaviors of structures are linear, nearly always.

Two classes of model have been developed for structural simulation. Nodal models, having nodal displacements as their variables, are the more common. They have the advantage of dealing naturally with structural discontinuities, localized masses, discrete springs, etc. Modal models, which have amplitudes of vibration modes (or other assumed shapes) as their variables, are less common, and they are best suited to homogeneous uniform or tapered structures. In post-failure simulation it is often necessary to have a zero-stiffness bending spring at the failure position, which is best treated by a nodal model. In a nonlinear problem, modal models contain many product terms, wihch rapidly complicate the calculations as one increases the number of modes used. Therefore, nodal models are by far the first choice for structural disaster simulations.

Structural Simulators

Simulators dedicated to failing and post-failure structural dynamics are not used for operator training, because in real time the process is over with too quickly for him to have any influence on it. However, such simulators could be used for planning studies.

COMPOUND-EMERGENCY SIMULATION

Interactions of Emergencies

Each type of emergency can be an outcome of many sequential combinations of cause/effect. For example, a structural failure can result from combinations of such factors as hot or cold thermal stress (for example, from a fire outside a vessel), wind, gravity loading, pressure, vibration, fatigue, corrosion, etc. Another example would be afforded by a human error in valve operation in a petrochemical plant which would create a spill of a combustible liquid, potentially producing or feeding a fire or explosion, which in turn could cause other emergencies in the plant equipment and their contents. Another example would be a fire in a power plant which would cause structural failure of a pipe or vessel, releasing radioactivity or a combustible fluid (e.g., lube oil). More such examples are given in Table 1. The interactions of unit emergencies are block-diagramed in Figure 2.

The simplest way to deal with sequences and interactions of emergencies, such as open and closed paths in Figure 2, is to set up a 3x3 matrix of discrete-event transition probabilities between pairs of the processes in Figure 2. Then one can use Monte Carlo simulation to determine the relative probabilities of various sequences and closed loops of emergencies.

Another approach to the many emergencies shown implicitly in Figure 2 is to set up a very general simulation for each block and interaction in the block diagram. Then by proper choice of parameters one could attempt to simulate an extraordinarily broad class of cases. For example, one could try to generate all of the simulations in Table 1 by mere choice of parameter values, all from the same overall model. This approach is "parameterization." It is very economical of programming, and it permits quick changeover of problems.

All of the foregoing compound emergency simulations are conceived to be of the continuous type, since continuous processes are being represented.

On a larger geographical scale, such as city-wide, discrete simulation can deal efficiently with large numbers of interacting unit emergencies. Essentially the same techniques are used in war gaming. Stochastic simulation campaigns may be used to derive good plans and policies.

Compound-Emergency Simulators

A special case of discrete simulation, called "parasimulation" by Perley,[21] uses a tree of possible system states in applications such as civil defense. It is useful in procedural trainers which do not have a requirement for dynamic realism of displays.

Within a given category of system to be simulated, a wide variety of specific situations can be established by parameterization, making it less often necessary to change programs. Clever parameterization will allow any one program to have wider applicability and thus better cost effectiveness. When a greater variety of systems is to be simulated than can be comprehended within one model by parameterization, it is necessary to use more than one model, each parameterized.

It can be predicted confidently that products of the class of "SAFER"[22-24] will spring up for unit emergencies other than toxic clouds. Moreover, these products will evolve to attain the capability of simulating more than one type of emergency by selection and even simulating compound emergencies. Other than logic models of safety systems within the systems suffering emergencies, these simulations would be mainly of the continuous type.

Much more progress has been made in the development of discrete system simulators of emergencies, such as civil disasters and ground battles. They are used for planning, training for disaster management, and training for planning.

Emergency Planning Canada has funded a study of a "2CX" system by Goodwood Data Systems, Ltd., Canada, in which war gaming technology is being applied to emergency planning and training. One of the possible directions of growth of the 2CX system is incorporation of a discrete simulation of the disaster or environment of concern.[8] This work could lead to development of dedicated discrete simulators, for research or gaming studies or management training, in large scale disaster or civil emergencies (floods, area fires, nuclear strike, etc.), in which processes are collapsed into natural or commanded discrete events, and in which spatial detail is aggregated enough to be tractable.

Applications of computer-aided learning (CAL) by Goodwood are using such software as PLATO (University of Illinois) and NATAL (National Research Council, Canada)[21] especially for the city-wide scale of disaster management.[8]

Computer graphics, notably the ROSS system[37] and the graphics used in the SAFER product,[22-24] would add a powerful ingredient to disaster simulators of all types.

The probable future requirement to incorporate compound emergencies will impose need to develop much more complex simulations in discrete-system emergency simulators than currently exist.

CONCLUSIONS

1. A noteworthy amount of scientific progress has already been achieved in the development of a technical basis for simulators of emergencies. One can therefore expect a substantial growth in the numbers and variety of simulators, either dedicated to or involving the simulation of emergencies of several kinds. The desirability and feasibility are clear, and the obstacles and difficulties seem to present nothing new to the simulator industry. The result should be a reduction in the public threat of emergencies of most types through improved training and planning.
2. For simulator manufacturers the time is ripe for a rapid expansion of effort in addition to a greater variety and severity of emergency simulations to existing simulator types, such as process operator training simulators and well drilling training simulators for use in planning studies.
3. Discrete simulation has been applied much more frequently in programs run on general purpose computers than in dedicated simulators. However, a strong growth in dedicated discrete simulators is to be expected, because computers small enough to be dedicated keep decreasing in price, and because a dedicated computer can have a more elaborate man-machine interface designed for use in a simulator for training or planning.
4. Nearly all continuous and discrete simulators have been entirely distinct from each other, few having had any features of the other. In the future, however, each type can be expected to incorporate more features of the other, each where it serves best, in powerful blends, as explained herein for the case of process operator training simulators.

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TABLE 1

Models Of Emergencies

	Subsystems		
Situation Characterization	Combustion and Firefighting Effects	Release and Fluid Propagation	Structural Response
Plume Dispersion	None	Plume transport and diffusion in atmosphere	None (assume rigid stack)
Stream Dispersion	None	Pollutant transported and diffused (and perhaps reacted chemically) in stream	None
Refinery or Tank Farm Fire; Leaking Oil Vessel	Oil Combustion Outside a vessel	Oil Leaking from a vessel	Fire Damaging the vessel
Pipeline Leak and Fire	Fire Outside Pipeline	Leakage from Pipeline	Fire Damaging Pipeline
Ship Leak and Fire	Fire on the Water	Combustible Fluid spreads on Water, burns, evaporates, etc.	Fire Damaging Ship
Fire in a Room or Truck or Railroad Car or Airplane Interior	Gases burn if above Kindling Point	Hot Combustible gases released by Solid Materials are Convected Upward	Structural Members Weaken and fail
Wildlands (e.g. brush or forest) fire; or Total Inner City Fire	All combustibles Burn	Wind Drives Flames	None; or Buildings Collapse
Wellhead Fire or Gas Station fire	Oil or gas from well burning	Oil or gas coming up out of well	Equipment at wellhead is damaged
Skyscraper Fire	All Combustibles (lumped by floors) burn	Hot gases seek to rise to next floor above	Structure in several floors is damaged
Coal Pile Fire	Heating from oxidation; combustion in each finite layer separately	Hot combustible gases rise, air in	None
Mine or Corridor Fire	Walls and Ceiling burn	Gases travel longitudinally and upward	Walls are damaged
Radioactivity leak in Power Plant	None	Progressive transport and mixing and diffusion inside and outside plant	None
Flood	None	Water rushes down a river bed	None
Spill on Ground (Truck or Train Accidents, e.g.)	None or on the Ground	Leakage onto ground, overland flow with insoak	None

TABLE 2

Some Usages Of Simulators Of Fires

Type of Organization	Usages
National Bureau of Standards Insurance Companies Research Institutes	Research simulations of fires in various combinations of building materials and construction schemes to assess from the standpoint of fire and to establish design guidelines and building codes
Fire Departments In-plant Fire Brigades Industrial Safety Departments	Simulations of fires in areas of responsibility, in order to develop fire-fighting plans, strategies, tactics and policies having local applicability
Firefighting Industry Regulatory Agencies	Simulations of fires to evaluate the theoretical performance of proposed new fire-fighting products
U.S. Coast Guard Environmental Protection Agencies Port Authorities Fire Departments	Simulations of fires resulting from spills of flammable liquids from ships in ports, to develop hazard control and response measures
Federal Emergency Management Agency Local Disaster Groups and Emergency Response Teams	Simulations of widespread urban fires in order to develop plans and policies
Research Organizations	Simulation for purposes of identifying initial conditions of a specific fire or parameter values for a portion of a dynamic fire model

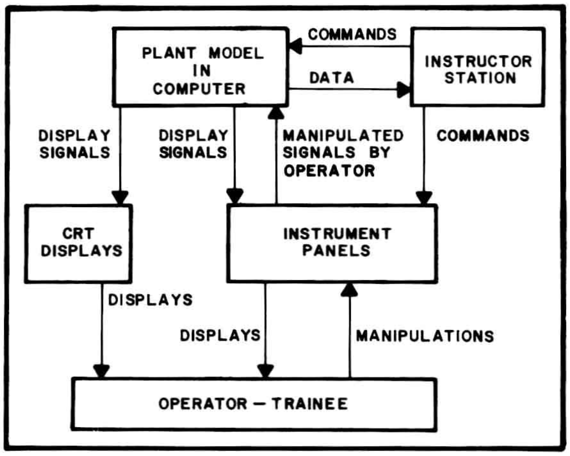

FIGURE 1

FUNCTIONAL BLOCK DIAGRAM OF

OPERATOR TRAINING SIMULATOR

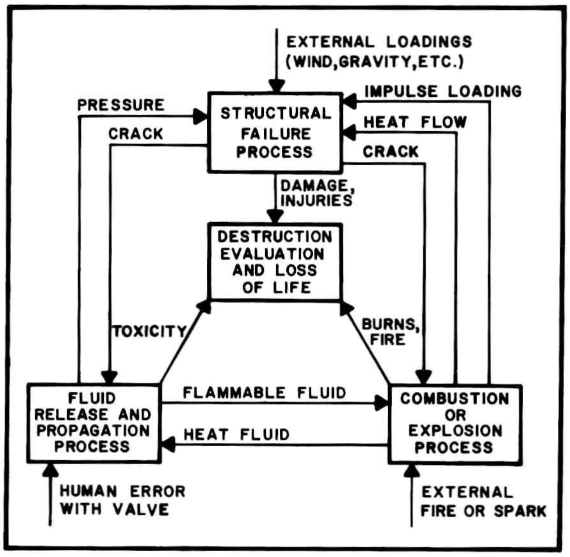

FIGURE 2

INTERACTIONS AMONG EMERGENCIES