CEMPS: A prototype spatial decision support system to aid in planning emergency evacuations

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CEMPS is a prototype spatial decision support system which links the topographical support and analysis provided by a geographic information system, ARC/INFO, with the ability to simulate the dynamics of an evacuation process. CEMPS has been designed to enable emergency planners to experiment with different emergency evacuation plans in order to devise a plan which meets their requirements. ARC/INFO is used to parameterize a dynamic simulation with topographical information and to display its results. The prototype runs on a Sun SPARCStation cluster but could be modified to run on other hardware and software.

Introduction

Planning emergency evacuations

Large scale emergencies can arise from a range of causes which may be natural or man-made. Natural hazards include hurricanes (such as Hurricane Andrew which hit the USA in 1992), earthquakes (such as those which affected Kobe in Japan in 1995), volcanic eruptions (such as Mount Etna in Italy in 1991 and 1993) and floods (such as those which so regularly afflict the coastal regions of Bangladesh). Human actions have led to a great increase in man-made hazards in the latter part of the twentieth century. Examples include the risk of large amounts of radioactivity being released from nuclear power generating plants such as occurred at Chernobyl, Russia in 1986 or of materials escaping from chemical plants, such as happened at Bhopal, India in 1984 when poisonous gas spread across a populated area.

Emergency planners are given the task of ensuring safe and rapid evacuation for, possibly, many thousands of people in the event of such a disaster. They must plan for and organize the movement of people and vehicles from dangerous and contaminated areas into safe zones. As might be expected, managing the logistics of these evacuations is a major task and one which can benefit greatly from computer-based decision support. Two areas in particular which might benefit from computer-based decision support are:

- real-time emergency management
- contingency planning for possible future evacuations.

This paper describes the development of CEMPS (Configurable Emergency Management and Planning System), which is a prototype spatial decision support system (SDSS) that is intended for use in contingency planning for emergency evacuations. The process of evacuating people from a hazardous area is dynamic. In what is usually a rapidly changing situation there are many uncertainties (Zeigler et al 1981). For example, when vehicles break down they may block an evacuation route, or previously safe routes may become unsafe. This fraught and messy evacuation process can be managed better if the emergency planners have had the chance to develop contingency plans. One role of modelling, as developed within management science, is to try to foresee the consequences of actions before taking them (Pidd 1996).
Large-scale evacuation involves the movement of people, sometimes against their wishes, to safe places. The behaviour of these people is crucial to the success of the evacuation but it is likely to be affected by fear, uncertainty, and the speed at which things occur. In most countries, the bulk of such evacuations involves motor vehicles travelling along existing roads that are controlled by police, armed forces, and militia, and along which one-way corridors will be established. Computer simulation methods offer an attractive way of modelling these evacuations because they permit the modeller to build in what is likely to be realistic behaviour rather than make unrealistic assumptions for the sake of easy computation. As an example, a back-of-the-envelope calculation using average evacuation rates may be very misleading if it assumes that the whole population receives information at the same time or if it assumes that the population believes what it is told. It is clearly important, when planning for an evacuation, to ensure that the plans are based on realistic assumptions.

The basis of CEMPS is a GIS which stores topographic data in a digital form. From this data, maps can be drawn and roads and other routes may be plotted. Much of the topographical information about the terrain of Europe and North America has been digitized in this way and thus, given the right databases, it is possible to produce maps of specified regions with relative ease. This presents a major opportunity for evacuation planners to use dynamic simulation methods in their planning. One of the drawbacks of simulating such evacuations has been the massive cost involved in building a database of the roads and buildings within an evacuation area. This data is already available in a GIS and thus can be used to parameterize a simulation model of the evacuation. With care, the simulation model can be designed so as to allow experimentation with evacuation plans which make realistic assumptions. Thus CEMPS harnesses the data handling capability of the GIS and links this to a discrete simulation to allow the comparison of evacuation plans.

Spatial decision support systems
Recent years have seen the emergence of the concept of SDSSs which are of interest to planners and others involved with managing and controlling resources within geographic areas. SDSS are based on the linkage of two concepts:

- geographical (or spatial) information systems which make use of digitized data that represent geographical information
- the analysis techniques often found in conventional decision support systems (DSS).

The idea is to link the powerful data representation features of a GIS with the analytical power of a DSS in order to aid in the exploration, structuring, and solution of complex spatial problems. When these problems are well structured, for example in the static allocation of space, then mathematical methods such as mathematical programming can be built into the SDSS. If statistical models need to be built, for example to analyse the distribution of motor neurone disease in different regions (Gatrell et al. 1991), then these too may form part of the SDSS. In CEMPS, the analytical power is provided by a dynamic simulation which allows the planner to see how an evacuation plan might work out in practice.

Densham (1991) argues that a typical SDSS has four components:

1. A set of analytical tools: to enable the user to investigate patterns in data and to explore hypotheses;
2. Decision modelling support: this goes rather further than the provision of analytical tools since it enables the user to carry out "what-if" investigations in order to explore the consequences of possible decisions;
3. A user interface: high-powered analytical and decision support tools are not much use if their application requires arcane commands made up of easily forgotten words to be memorized, so a friendly user interface is fundamental to SDSS;
4. An underlying geographic database: this provides the bedrock on which the analysis and decision support proceeds.

Many contemporary GIS come with built-in analysis tools in addition to their data storage, and manipulation and representation tools and can
provide many of the features needed for a SDSS. The addition of decision modelling tools which employ analytical methods can turn a GIS into a fully-fledged SDSS. This route was the one taken in developing CEMPS, for which the impressive built-in capabilities of the ARC/INFO GIS (ESRI 1993) were used as the basis of the SDSS and the simulation and link routines were added to enable dynamic modelling. Thus, as shown in Figure 1, CEMPS consists of three main components:

1 A generic traffic simulation model: this consists of the analysis and decision modelling components. The generic model is parameterized for particular applications by taking data from the geographic database;
2 The database: this provides the relevant spatial data in a convenient and consistent form for easy downloading;
3 The user interface: this facilitates the user’s interaction with the rest of the SDSS. Clearly this interface will depend on the computer hardware and operating system being used.

Computer simulation methods

Computer simulation methods involve experimentation on a model of some system of interest (Pidd 1992a) rather than on the system itself. They are especially well suited to systems which involve a great deal of uncertainty and in which there is considerable interaction. One of the drawbacks of the use of computer simulation methods is that they are computationally very demanding when there is a large number of interacting entities. This is particularly important when considering the simulation of large scale evacuations in which populations numbering tens or hundreds of thousands may need to be moved to safe areas. Thus, to be used in evacuation studies, the simulation system needs to be efficiently written or it may run so slowly that it is of limited use.

With such SDSS, the idea of including a computer simulation of evacuation plans is to enable a planner to carry out ‘what-if’ analyses so as to find some acceptable evacuation plan. In most circumstances, it is impossible to test a range of evacuation scenarios on the real population and a simulation provides the only opportunity to assess the dynamics of evacuation plans. Other than experimentation on the real world, the only other option is to estimate average evacuation rates and average compliance rates in order to come up with some estimate of expected evacuation time. Needless to say, such a use of average values hits the usual problems of stochastic variation that is often found in studies of queuing systems (see Cox and Smith (1961) for example). This can lead, for example, to gross mis-estimates of queuing times and actual service levels. Hence, computer simulation methods offer a useful way to investigate possible evacuation plans.

A simulation study is, however, no better than the model which lies at the heart of the simulation. In its simplest terms, such a model consists of logic and data, and in the case of an evacuation simulation, the logic consists of the rules by which vehicles and other objects move along an evacuation route. The evacuation routes themselves are, as are other aspects of the ‘physics’ of the system, data.
which can be read by the simulator. Thus a simulator can be constructed which would cope with traffic movements along a general type of road network. The actual detail of the precise network to be simulated could be read as data by the simulation programme.

In the case of large-scale road networks, the number of arcs and nodes needed to represent the road network may be quite high and the associated data which provides map grid references for each point on the road will also be large. Thus, to establish a basic data set of road network data for a simulation of this type can require considerable effort. The idea of using a GIS such as ARC/INFO was, in part, due to a desire to reduce the data management problems inherent in simulations of this type. The data is already available within the GIS so why not make use of it in a simulation of the evacuation?

**Approaches to evacuation simulation**

A detailed description of the methods which are usually employed in the development of evacuation simulators is given in Pidd et al (1996). Broadly speaking, there are three approaches commonly used when developing such models. The basic methods are those which might be employed in any reasonable scale simulation of traffic moving around a road network.

**Macro-simulators**

Macro-simulators are ones in which traffic movement on an arc is often modelled as if it were a fluid flow that can be represented by fluid dynamics equations which can be updated at regular intervals in a time-slicing approach to simulation. The main advantage of these simulators is that they are relatively undemanding from a computational viewpoint and this makes them useful for real-time studies. Their main deficiencies relate to the crude nature of the approximation involved in assuming a fluid-flow analogy. In particular, there is no obvious way to incorporate stochastic events such as vehicle breakdowns. Examples of this approach are NETVAC1 (Sheffi et al 1982), CLEAR (McLean et al 1983) and MASSVAC (Hobeika and Jamie 1985) and its derivatives such as MASSVAC2-MOVOPL (Southworth and Chin 1987) and REMS (Tufekci et al 1993).

**Micro-simulators**

Micro-simulators are the opposite extreme from macro-simulators in that they attempt to model the detailed movement of individual vehicles or other objects. Thus, a micro-simulator needs to keep track of the attributes of all such moving objects, including their speed, position, and route choice at any given time in the simulation. The snag with micro-simulators is that they may involve considerable computational demands when there are thousands or tens of thousands of such objects to track during an evacuation. The advantage is that random events such as breakdowns are simple to incorporate, as are realistic, but apparently irrational, human reactions. Comparing like with like, a micro-simulator is likely to run slower than a macro-simulator and thus a micro-simulator is unlikely to be well suited to real-time modelling. However, they can be used in contingency planning and examples of this are NETSIM (Peat, Marwick, Mitchell and Co. 1973) and SNEM (Stern and Sinuaty-Stern 1989).

**Meso-simulators**

These lie somewhere between macro- and micro-simulators and attempt to deal with movements around a road network by grouping objects into packets or convoys which are assumed to stay together. The aim is to reduce the computational workload whilst still retaining, in theory at least, the ability to deal with some detailed stochastic events. Examples of such meso-simulators are PREDYNA-DYNEV (FEMA 1984) which was further refined into FEMA's Integrated Emergency Management System (Jaske 1986; Bower et al 1990) and a simulator designed for real-time use in traffic management on urban road networks (Barcelo and Grau 1993).

The CEMPS prototype

The prototype of CEMPS (Configurable Emergency Management and Planning System) was designed for the contingency planning of large-scale evacuations from incidents which, due to their severity, might require the rapid movement of many people from danger zones to safe areas. Thus, possible scenarios may be examined and contingency plans developed and tested on a simulated evacuation using CEMPS. The idea is to encourage emergency planners to examine a range
of possible plans and scenarios rather than settle for a limited number which are straightforward to envisage and analyse but which might turn out to be poor should they ever be put to the test. An overview of the internals of CEMPS is shown in Figure 2 and is described here.

The simulator
The basic approach is that of a micro-simulator in which objects are tracked individually through simulated time. This approach was adopted so as to enable stochastic events to be simulated, should that be necessary, and also to enable a range of behaviours in the population to be modelled, should that also be important. Detailed descriptions of the simulator are given in Pidd et al. (1993; 1996).

Choice of language for the simulator
The simulation was developed from a simple library of routines written in C++ (see Pidd 1992b). The language was chosen because it is object-oriented, widely available, relatively standardized, and supposed to be easily portable between different platforms. In fact, the claims of portability and of standardization turned out to be something of a myth, because standards are continually shifting and different compiler vendors have the habit of adding their own extra features. This became clear when the library, which was originally coded and debugged in Borland Turbo C++, was ported across to SunOS on a Sun SPARCStation. To enable this port to succeed, considerable use was made of compiler directives to ensure satisfactory cross-platform compilation.

The main reasons for an object-oriented approach in this type of modelling are discussed in Pidd (1995). At its heart, the simulator of CEMPS is a road traffic simulation in which objects (people and vehicles) are moved around a defined road network according to acceptable rules for traffic flow. In object-oriented terms, the moving objects and the network on which they move can be considered as classes of objects. Once this is done, a careful design of the classes enables each class to be specialized by inheritance mechanism. Thus, for example, the base class for the moving objects might be a MovingObject class and, via inheritance, this class might be specialized into realistic descendant classes such as Vehicle. In turn, the Vehicle class might be specialized into sub-classes such as Car, Truck, and Bus. If the basic movement of a moving object is modelled in the MovingObject class, then its descendants can inherit this and may modify it in a safe way.

With this approach to modelling in mind, it seemed sensible to take the object-oriented route. The research team did not have access to SIMULA (Dahl and Nygaard 1966), the simulation language which first embodied the ideas of object-orientation and, at the time, the only other available object-oriented system was MODSIM (CACI 1996) and no budget was available for its purchase. In addition, the CEMPS simulator required only a
fraction of the facilities provided by such fully-fledged simulation systems. Thus, the simulator was developed in C++, a language which supports all the important features of object orientation (Wegner 1990).

The simulation classes
As discussed above, an object-oriented approach is ideal for this type of simulation since it allows a software developer to produce a general purpose library which may be safely extended to suit particular applications. This is achieved via inheritance mechanisms which allow new variable types to be safely defined together with their possible operations.

In the case of CEMPS, the road network is defined hierarchically as follows:

- the fundamental idea is that of a Location, which may be of variable size and that may be occupied by one or more vehicles
- an arc, or length of road, is a linked list of Locations, thus objects may move from Location to Location according to whatever rules govern their movement. Locations may also be specialized by inheritance, for example to form a Junction
- the road network is then represented by a list, or tree, of arcs that are connected at junctions.

Hence, if the GIS database contains the information that defines the road network, this may be very quickly transformed into the classes and objects needed by the simulation.

As discussed in the previous section, vehicles are also defined from a class hierarchy. Vehicle objects also need to be dynamic since they must move from location to location. Thus, in the standard terminology of discrete simulation, these are simulation entities. Their class is one which jointly inherits the idea of a moving object and the

![Diagram](image-url)

Figure 3. The links between the GIS and the simulator within CEMPS.
idea of a simulation entity class, which is itself defined in the basic C++ simulation library.

Platform portability
The simulator is object-oriented and is written in C++ to run, in the CEMPS prototype, on a Sun SPARCStation. Given the wide availability of C++ compilers, the simulator part of CEMPS could be run on many different types of hardware and in a range of operating systems. However, as mentioned earlier, it should be noted that porting code between different operating systems may take longer than enthusiasts might suggest, and a degree of caution would seem justified.

The GIS – ARC/INFO
ARC/INFO is a commercially available GIS which, in the case of CEMPS, was implemented on a Sun SPARCStation. The geographical data are stored in vector format as what are termed coverages, which are spatial data clusters stored as layers of data that describe special features of an area as arcs, lines, nodes, and polygons. For CEMPS, ARC/INFO serves two purposes, firstly as a topographical database and secondly as a display mechanism (Figure 3).

CEMPS makes use of three types of ARC/INFO coverages:
1 Road network data are stored as are/line coverages. An arc is used to represent part of a road and the arc has nodes at its ends. In most cases, the nodes are used to represent road junctions, which, in the simulation, can be made specific by the object-oriented features of the simulator;
2 The data which describe evacuating entities (for example, people, vehicles), emergency vehicles, and resource centres are stored as point coverages whose locations may change during the simulation;
3 The areas from which and to which people may need to be evacuated (evacuation zones) are stored as polygon coverages as these represent physical areas.

The three types of coverage are inter-related within an evacuation simulation. For instance, entities which are to be evacuated are assigned to initial starting points on the section of road closest to their 'proper' locations. This determines the road along which an entity will embark on its journey towards safety. The roads in turn are linked to evacuation zones so as to permit phased evacuations to occur.

As can be seen from Figure 3, ARC/INFO includes modules such as ARC and NETWORK which provide functions which are used by the simulation model. ARC, for example, provides allocation functions which may be used to relate the point, polygon, and line data to the locations needed for the evacuation simulation. NETWORK (a network allocation module) also provides built-in functions which are used within CEMPS. Examples include:

- ROUTE, which evaluates selected routes within a road network on the basis of specified criteria such as time, distance, and capacity
- ALLOCATE, which can be used to allocate resources based on criteria such as the capacity of centres (selected nodes) and their locations.

In the CEMPS prototype, the NETWORK module is used in preparing the topographical data for use by the simulation. For example, in establishing routes and distances to the destination point from each node (junction) in the network. Future interaction links might allow the use of NETWORK functions to be used as the simulation runs so as to permit, for example, choice of routes by evacuating entities to be varied during simulation execution.

Thus, the simulation model has been designed to use the concepts of arcs (roads), nodes (junctions), and points (evacuating entities) which correspond to the data structures of ARC/INFO and similar GIS.

The operation of the CEMPS prototype
Entities and route finding
In the prototype, the entities to be evacuated are treated as if they are vehicles which need to be moved along the road network from danger zones to safe areas. The details of any specific road network are read directly from the GIS and it is thus possible to simulate any road network for which ARC/INFO files exist at the required resolution. An arc or series of arcs is used to represent a one-way street. At its simplest, such a street has just a single lane or carriageway and thus no overtaking would be possible. Specialization of the simulation objects
allows such streets to have multiple lanes which do permit overtaking if that is needed in the simulation. One-way traffic flow is considered normal in evacuations from major incidents because traffic is usually directed *en masse* away from the hazard and towards safe areas. Vehicles moving in the opposite direction are likely to be from emergency services teams and they are most likely to follow pre-assigned routes which are closed to the general public.

As discussed earlier, CEMPS employs an object-oriented micro-simulator in which objects move around a road network. The moving objects are independent of one another except when they need to contend for road space. This will occur when a *Location* is full at a time when other vehicles wish to move into it in order to progress along an arc and towards its destination. It is therefore clear that the simulation must incorporate rules to govern route finding and resource contention. In CEMPS this is achieved in two simple ways.

It should be noted, at this point, that CEMPS was never envisaged as a commercial or immediately useable product. The idea was to investigate the linkage of dynamic simulation models to GIS so as to help emergency planners. Hence, it employs rather simple ideas about route finding and resource contention. The basic route of a vehicle is planned before the simulation starts by the use of the ARC/INFO NETWORK module. Rather than planning a route in detail, the NETWORK module is used to find the closest safe destination for the objects. The objects then proceed to this destination as the simulation proceeds.

The within-the-simulation route finding employed for each moving object is myopic. Vehicles proceed along an arc in the direction of their allotted destination until they reach a junction. At the junction, they take the best route possible to bring them closest to their destination unless they are blocked by congestion at that junction. If they are so blocked, then they take the next best route, and so on. If all are blocked, then they must wait their turn.

Though this may seem a far too simple approach, it may not be so foolish in the context of a real evacuation. In such circumstances, the police and other authorities are likely to place tight control of feasible routes and vehicles may have little choice but to take the defined routes and to wait whenever it is congested.
Links between the simulator and the GIS

Rather than write special purpose graphics routines which show the progress of the simulated evacuation on-screen as it proceeds, CEMPS uses the built-in graphics facilities of the GIS. This works as follows at specified intervals during the simulation:

- the coverages which correspond to the vehicles are updated by the transfer of data relating to their current position from the simulator to the ARCIINFO system
- the built-in plotting functions of ARCPLOT are then activated in the output module so as to re-draw the screen and thus to show the new positions of the vehicles on-screen.

This apparently simple mechanism required the development of special routines which are written in C and in ARCSDL (The ARC Software Development Language). The routines update the coverages by invoking built-in functions from INFO and ARCEDIT. Once the coverages are updated, the plotting functions of ARCPLOT can be used to re-draw the screen. The more often the screen is updated, then the slower the simulation will run. Screen dumps of run-time output from a simple simulation are shown in Figures 4 and 5, and such output can be used to display the progress of the evacuation as it proceeds.

The Heysham Data set

The initial link between the micro-simulator and the GIS was established and tested using a simplified data set with a rectangular road network. This test data set was then replaced with one, referred to here as the Heysham Data set, based on the area around Lancaster University. The use of the Heysham Data set was crucial to the development of CEMPS. It enabled the simulator to be developed to fit the types of road network that are found in the real world. The Heysham Data set was used partially because it covers the area around Lancaster University (local to the authors of this paper), but also because the village of Heysham is the home of two nuclear power plants. These present a potential radioactive hazard and the surrounding population would indeed be evacuated in the event of a major incident. The Heysham Data set covers the population of the Lancaster district (a population of over 100,000) within a circle with a radius of approximately 25 km. It is used to test and

![Screen dump of a CEMPS simulation in progress.](image-url)
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demonstrate the basic functions of CEMPS and the
screen dumps of Figure 4 and Figure 5 are from a
simulation using that data set.

There were several sources for the Heysham
Data set. The original Heysham line and polygon
data which represent the terrain, rail, and
transmission networks were already available for use
as captures of digitized Ordnance Survey maps. The
road network came from the Pinpoint Road
Network and the population/address data came
from the Pinpoint Address Code. Radial sector
and plume dispersion data were supplied by the
Lancashire County Council's Emergency Planning
Unit. Initial traffic loading and other scenario-
specific data were specially created from the
Pinpoint Address Code data set.

Data preparation for simulation using the GIS
data sets
Before any simulation can be performed, the
coverages need to be established in the ARC/INFO
data files. As mentioned earlier, the basic
topographic data, such as that describing the road
network, can be read from existing ARC/INFO files
but it is also necessary to place the evacuees on
the network. This is done in ARC by computing their
proximities to the roads on the network and then
assigning them to their nearest road segment as the
start points for their evacuation. They are then
linked to their assigned destinations (the safe areas)
by using the allocate function provided by the
NETWORK module. Thus, the distances from
current location to destination can be calculated. In
like manner, evacuees can be allocated to evacuation
zones from which phased evacuations may be
planned so as to minimize initial congestion.

A known problem with evacuation simulators
is that data preparation presents a huge burden
because it is necessary for the input data to capture
the terrain on which the simulation will be
conducted. CEMPS is configurable because it reads
its data from ARC/INFO files and then converts
them into the form required by the simulation.
Thus, providing the data contained by the GIS had
been properly validated, the simulated terrain over
which the evacuation is modelled should itself be
valid. This reduces the work needed for data
preparation for this type of dynamic modelling.
There is no need to prepare huge amounts of special
data and there is no need to run expensive validation
tests on this special data. CEMPS makes use of
existing geographic data that has already been
validated.

The operation of CEMPS
CEMPS is a fully menu-driven SDSS which provides
several features that can be used for contingency
planning. It provides the following options:

- the analysis of shortest routes to each shelter
destination
- querying radial zones (defined according to the
  radial distance from the hazard source)
- analysis of population distribution
- simulation experimentation
- querying emergency planning information –
  such as that regarding the radioactive plume
- querying shelter capacity status and location
  information
- querying the traffic load on roads
- querying the data sets
- population loading (allocation to traffic
generation points) for evacuation.

These enable the user to modify the scenarios and to
investigate the results of different simulations.

Discussion
The CEMPS prototype was designed to simulate
evacuation plans for potential emergencies. It is
intended to be general in the sense of being able to
simulate evacuation on almost any road network,
and yet also detailed enough to allow realistic
assumptions to be used for planning. This
generality is achieved by using an existing GIS as the
source of data about the road network. The detail is
achieved by the use of a purpose-built, object-
oriented micro-simulator. In its prototype form,
CEMPS has been used to carry out simple
simulations in the area around Lancaster University.
The screen dumps shown in Figures 4 and 5 are
taken from one such run of the local simulation.
Thankfully, there has been no need to evacuate the
area around the nuclear power plants in this area
and therefore there has been no opportunity to
assess the accuracy of the simulation that forms part
of CEMPS.

Since CEMPS has only been used to examine
simple scenarios, it would be meaningless to quote
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statistics such as run-time in minutes. These depend on variable factors such as the scenario being investigated, the degree of detail required, and on the computer hardware and operating system being used. In addition, it should be noted that the design aim was to produce an interactive planning tool. Thus, the intention is that planners should be able to watch a simulation proceed and should intervene as and when necessary. CEMPS is not a simulator that is designed for multiple runs of large scenarios. Rather, it is a tool to support decision makers as they think things through and in advance of any real incident.

CEMPS uses ARC/INFO as its GIS for two, straightforward reasons. Firstly, it was readily available at low cost and, secondly, one of the authors of this paper had considerable experience in its use. Not only was ARC/INFO available and supported, but it also had convenient road networks stored in its INFO database. Thus its attraction for use in a prototype is fairly clear. However, there were significant snags which appeared during its use in developing CEMPS.

The coverage files used by ARC/INFO are not transparent and yet they need to be manipulated to produce the required graphical output if the GIS is to be used for that purpose. The only way to achieve this, given the version of the GIS in use, was to write low-level routines for these file operations. This was further complicated by the fact that, as used in CEMPS, ARCSDL is based mainly on FORTRAN but the simulator is written in C++, which has a storage structure based on C. The C and FORTRAN structures were not compatible and this makes it necessary to carry out file operations at a low level.

The use of ARCPLOT to display run-time graphical output as the simulation proceeds saved time during the development of the CEMPS prototype, but it can result in very slow running of the simulation. There are two reasons for this. Firstly, screen updates slow down most programs, especially when the screen is very detailed. Secondly, the screen updating had to be achieved by updating the coverage files which are physical devices. Thus this repeated file access leads to slow running if there are many such updates to be made as the simulation proceeds. A user is faced with a trade-off between faster running, which means fewer updates and therefore poorer access to the current state of the simulation, and frequent updates to on-screen system state, which leads to slower running.

Both of these problems might be resolved by the use of a different GIS and by a tighter linkage between the simulator and the GIS. However, this would lead to a system which is not as general as CEMPS and one of the aims of its development was to show how a GIS could be linked to a simulation so as to form a SDSS.

Further developments

Route choice

As described earlier, route choice of individual evacuees is based on a myopic view of congestion which modifies pre-existing route preferences. The route preferences are computed at the start of the simulation by computing shortest paths from each road junction to the destination area. This simple approach is probably justified if the evacuating vehicles are to be permitted to select their own routes in a real evacuation. However, in many evacuations route choice may be strictly confined by the presence of police and/or armed troops who may instruct vehicles to follow particular routes regardless of apparent local congestion. This instruction may be based on wider information (for example helicopter views of total congestion) available to those directing the evacuation, enabling them to see that once a bottleneck is passed, movement may be swift and safe.

This traffic direction is not a feature of CEMPS but could be provided by ensuring that route choice is determined by instruction from some exogenous controller who has a total picture of the current state of the evacuation.

Specialized junctions

The prototype of CEMPS treats road junctions in a simple-minded way: vehicles compete on a first-come-first-move basis for the road space in a junction. This may in fact be reasonable in an evacuation if the movement of vehicles is tightly controlled, even if the drivers have some myopic route choice. However, it would probably be useful to use the object-oriented features of the simulator to develop specialized versions of the general junction to cope with features such as roundabouts (traffic circles). In order to put this into practice, information about the types of junction would need to be included in the GIS and this may not always be the case.
Different hardware and software platforms

The prototype of CEMPS was developed on a Sun SPARCStation cluster because a fast computer was needed which supported a widely used GIS. Since work began on CEMPS, ordinary PCs and their operating systems (notably OS/2 and Windows NT) have become much more sophisticated and, indeed, many of the software development tools for these computers have become much easier to use and are very powerful - even when compared to UNIX-based computers. Thus, it would be sensible to port the CEMPS prototype to other computer systems. This, in turn, makes it much more likely that the approach embodied in CEMPS will be used by emergency planners, most of whom do not have access to UNIX-based computers.

Model validation

The validation of simulation models is always a difficult task and there have been many suggestions about how best to proceed in this area. Zeigler (1976) recommends that models can only be validated against specified experimental frames which place the model in the context of its intended use. This assumes that there is no such thing as a simulation model which has general validity. A more extreme view is taken by Paul and Hlupic (1994) who argues that, in general, model validation is impossible - certainly in the sense of being sure that the model will always operate as intended.

Both of these viewpoints highlight the difficult task of validating any simulation model and, even more, the task of validating a model whose intended use is not yet fully determined. In the case of CEMPS, the simulator is intended to be used at whatever level of detail the planner feels is appropriate and this, in turn, makes the specification of the experimental frame extremely hard.

In one sense, therefore, CEMPS has not been validated. It merely consists of a micro-simulator to mimic the movement of vehicles and other objects across terrain that is defined by a GIS. To be used in practice, the simulator needs to be refined and validated in a step-wise manner. This can proceed in a number of ways:

- the simulated times taken to move vehicles between two known points under defined traffic conditions could be compared with those found to be the case in real life. This forms a type of low-level Turing test in which the model output is compared with the system that it is intended to mimic. Even this low-level validation is not without its problems, however, since the degree to which the vehicle movement times are modelled accurately will depend on the experimental frame for the simulation experiment. It might actually be necessary to observe many thousands of vehicle movements, preferably ones with congestion across a road network, in order to have some degree of confidence - statistical or otherwise

The effect of control interventions in the model (for example the closure of certain routes) could be compared with the effect that these would have in real life. This major undertaking would help to build confidence in the model. It would only make sense when a low-level Turing test had already been conducted satisfactorily as discussed above.

This discussion illustrates the difficulty in validating any model of an intervention in a large system. This same problem occurs in many military simulations and it has been discussed at length by Balci and Sargent (1984) and by Miser and Quade (1988). Precisely the same issues would apply if CEMPS were to be replaced by a simple statistical model. The difference is, that for a simulator of the type employed in CEMPS, some form of low-level and mid-level Turing test is possible.

The effect of information

A further use of CEMPS might be to model the effects of making information available to the public. One problem in any large-scale evacuation is what information to make available to the public at what time. For example, the possible escape of a dangerous plume of gas presents enormous risks whether the escape actually occurs or not. If the public is to be warned whenever there is such a risk then one of two possibilities are likely. The first is unjustified panic. The second is a gradual slippage into disbelief if there are false alarms. The effect of information delays on the progress of an evacuation could perhaps be modelled by using a system such as CEMPS which had been modified to allow controlled publication of information.
Conclusions

The development of the CEMPS prototype shows that a SDSS can be constructed by the linkage of a dynamic computer simulation model to an existing GIS. This allows rapid configuration of a model which can be used to test evacuation plans. CEMPS itself requires further development before it becomes a practical tool, but it clearly demonstrates the validity of this approach to developing this type of decision support system.

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