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CEMPS: A CONFIGURABLE EVACUATION MANAGEMENT AND PLANNING SYSTEM - A PROGRESS REPORT.

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ABSTRACT

This paper is a summary of progress to date in developing a spatial decision support system to be used by emergency planners in preparing contingency plans for possible evacuations from man-made hazards. Its core is based on linking a static Geographical Information System with a dynamic micro-simulator of traffic movements. The idea is to permit emergency planners to interact with the system so as to improve the planning process.

1 INTRODUCTION

One feature of modern times is an increasing number of hazardous installations and sites across the world. Most of these have been built with the best of intents, usually as a way of supplying goods or energy to areas wider than their immediate locality. Examples might be; chemical complexes which handle and produce substances which are highly toxic or carcinogenic; and nuclear power plants from which, despite good design, there remain risks of radio-active leaks and even of explosion.

Given that contemporary society appears to need such plants, it is obviously of paramount importance that they are operated safely and that people living in the vicinity are protected from unnecessary risks. In addition, it is also important that plans have been laid to evacuate the areas around such plant, should it become necessary - for whatever reason.

Different countries appear to strike different attitudes to this problem of planned evacuation. Some regard it important to have sound plans to evacuate people from within quite a large radius of nuclear power stations. Others seem to feel that relatively limited evacuation would ever be needed. As an example, in the USA, it is apparently necessary for nuclear generation companies to have approved plans to evacuate within an approximate 10 mile radius, whereas in the UK the operators are only required to plan for evacuation within a radius of less than 1 kilometre.

Whatever the specified radius, and whether it is specified in legislation or has developed in custom and practice, it is clearly of some importance to ensure that any plans are soundly conceived and make realistic assumptions. For example, in the UK it is sometimes assumed that, in the event of a major incident in a nuclear generation plant, that people without cars will be evacuated by bus and taken to safe areas. This assumes that buses and drivers will be available within a short distance of the evacuation zone and also assumes that the drivers will be willing to drive into the zone to collect evacuees. Whether they will do this and possibly abandon their own families, is a moot point.

Devising an evacuation plan involves a number of tasks which include the following.

- Selecting safe destinations to which people and goods can be evacuated.
- Dividing the evacuation zone into a number of sub-zones so that the evacuation can be phased if necessary.
- Planning the movement of transport into the evacuation zone so as to remove the old, the sick and those without immediate access to their own transport.
- Selecting routes along which traffic will be martialled to safe destinations and also selecting routes for incoming vehicles.

The important issue, then, is to ensure that the zone can be safely evacuated within specified time limits.

2 SIMULATION AND GEOGRAPHIC INFORMATION SYSTEMS

Geographic and spatial data is routinely stored in a digitised form and may be accessed via Geographic Information Systems (GIS) which may be simple file organisers or may be fully fledged relational data bases with built-in analysis capability. It is clearly, therefore, sensible to make use of GIS when devising an evacuation plan. At the very least, a GIS provides a rapid way to examine the static aspects of an evacuation plan such as agreeing evacuation sub-zones and in considering evacuation routes.

However, important though the static aspects are, the dynamic aspects must also be considered. For example, how long will it take to get relief vehicles into the evacuation zones? How long will it take to evacuate the population to safe destinations. It is in facing these dynamic issues that simulation methods come into their own. For it is simply not enough to assume that, for example, average speed calculations can be used to estimate evacuation times. Vehicles break down, the police intervene, some vehicles may be re-rerouted, not all residents may leave at the requested time - some may go earlier and others may refuse to leave.

Hence it makes sense to try to marry the benefits of GIS and computer simulation methods. The GIS can be used to set up the arena within which the simulation is to be played and the simulation can be used to consider the dynamic interactions which come into being as an evacuation proceeds.

3 APPROACHES TO SIMULATION IN EVACUATION

In part, an evacuation simulator is a traffic simulator of the type which is used to try to improve traffic flows in urban areas. The idea is to show what happens as vehicles, and possibly people, move around a road network. Thus such a simulator must be able to cope with varying traffic levels, with route choice, with the differing capacities of various roads and with the possibility of blockages due to accidents and breakdowns. Broadly speaking there are three approaches taken to such simulations.

3.1 Macro-simulation

These simulations make no attempt to try to track the movement of individual vehicles or even of convoys of vehicles. Instead, they draw an analogy with fluid flows in pipes and are based around difference equations and differential equations which attempt to estimate the movement of vehicles in unit time intervals across a given road network. Well known examples of this approach include NETVAC1 (Sheffi et al, 1982) and MASSVAC (Radwan et al, 1985).

The main advantage of this macro approach to simulation is that the resulting model is not too demanding computationally. This means that models can be run very quickly, even on relatively low powered computer hardware and software. This make them attractive for real-time application when traffic is being directed from central police control units.

The main disadvantages of this approach are, firstly, that they are rather crude approximations in non-steady-state conditions. Most of the equations in use were developed to depict such steady state, but this is unlikely to be applicable in emergency evacuation. The second problem is that they do not make it easy to model the effects of random breakdowns and accidents which may occur and will disrupt traffic flow.

3.2 Micro-simulations

These take the opposite point of view and attempt to track the movement of individual vehicles as they move around the road network. These are thus well suited to conventional discrete event simulation in which the vehicles are represented as simulation entities whose state representation may include attributes such as their position in the network, their intended route and their current speed. They may also, obviously, be allowed to breakdown and block a route.

The problem with this approach is that large numbers of vehicles mean that the processing of events is computationally demanding and the simulation may run rather slowly unless the event processing is implemented with great efficiency. This probably means that, with currently available software and hardware, such simulators will be far too slow for real time use. However, they may be usable for purposes such as the planning of an evacuation. Especially one in which it is important to interact with the simulation as it runs.

3.3 Meso-simulators

This term is used for simulation models which take an approach some way between the other two. Typically they divide a traffic flow into convoys or packets of vehicles which are then moved around the network. They thus combine the advantages and disadvantages of the other two methods.

One exponent of meso approaches is Barcelo (1993) who describes a simulator which is intended to be part of a real time traffic control system in urban road networks. He argues that the simulator is fast enough for real time use, but has a fine enough scale to cope with non-steady-state. However, it seems unlikely that it copes with stochastic effects such as breakdowns.

4 CEMPS: A CONFIGURABLE EVACUATION MANAGEMENT AND PLANNING SYSTEM

The basic idea of CEMPS is shown in figure 1, which shows that CEMPS has two main modules.

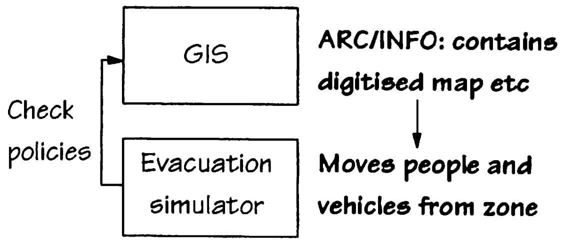

Figure 1: Basic idea of CEMPS

(1). A GIS: in the prototype under development, the GIS is ARC/INFO. In principle there is no reason why a different GIS could not be substituted for ARC/INFO should that become necessary. All that is required is that there should be some defined way to communicate with the data base of the GIS,

(2). A micro-simulator: in the prototype this is a bespoke simulator which is written in C++. As in the case of the GIS, it ought to be possible to substitute this simulator with another, were one to be found with equivalent or better functionality.

The prototype of CEMPS runs on a SUN SPARCStation and makes no unusual demand on the system hardware and software. It runs under Sun OpenWindows and consists of two main processes which communicate with one another. The first process is the simulator and the other is the GIS. The GIS is used to establish the starting data for the simulation - thus it provides the road network, the evacuation zones the safe destinations and the location of vehicles and population. The GIS is also used for display purposes so as to avoid the need to include graphics modules within the simulator.

Thus, the simulator runs in one window and it periodically communicates with the GIS data base by updating the position of vehicles on-screen. Thus the other (much larger) window shows the current state of the evacuation. As mentioned earlier, this approach avoids re-inventing the wheel of graphics, but does slow down the running of the simulator as it is necessary to update the files of the GIS data base whenever this communication takes place.

5 THE CEMPS MICRO-SIMULATOR

As this is a simulation conference, its seems sensible to discuss the bespoke micro-simulator which has been developed for CEMPS. Descriptions of this system at varying levels of detail are to be found in Pidd (1992a) and de Silva et al (1993). In essence, it is a three phase discrete event simulator which makes full use of the object oriented features of C++. As with all three phase simulations (Pidd, 1992b) its core logic revolves around two types of building block; Bs (or B activities) and Cs (or C activities).

5.1 Three phase simulation

Bs are used to represent those activities which can with some certainty be scheduled for the future on some event list. Cs are used to sort out the logical consequences of the Bs which are executed when their time arrives. Each C has a test-head which specifies the conditions (they are sometimes known as Conditional activities) which must be satisfied for the activity to occur. This avoids the cascade of if..else or switch statements which bedevil event based simulations. As all Cs are treated as potentially active at each time beat, it avoids having to decide whether processes are active or passive, as in process interaction.

Because the simulator makes full use of the object oriented facilities of C++, the core logic is reduced to a very small program. In essence, vehicles must be made to move, to stop, to breakdown and to be repaired - this all assumes that they have attributes such as speed, location and destination. Polymorphism allows different types of vehicle to interpret these Bs and Cs in different ways.

5.2 A problem with C++

One problem with the use of C++ and some other object oriented languages is that they do not, in fact, permit easy encapsulation in any proper sense. Proper encapsulation would have at least the Bs as member functions of the entity classes whose behaviour they modify. This is because the Bs are effectively event routines which prescribe the immediate effect of an event on a member of a single class of entity. Ideally, then, each descendent entity class would contain member functions which are the Bs of that class. These Bs could then be 'fired' by the simulation executive as and when their time approaches. Unfortunately such member function Bs are only possible if the base class of those entities has prototype member functions of the same name - that is, the base class needs to be edited each time a new B is added. This is somewhat against the principle of extensible software which is supposedly at the heart of object orientation.

5.3 The basic class hierarchy

The basic class hierarchy is shown in figure 2. As is usually the case in C++, all classes are made to descend from an abstract data type - known here as BaseType. An abstract data type does not have any instantiated objects but is used to allow later classes to be descendants of the BaseType. This is crucial for polymorphic use of overloaded functions in the simulation. Most of the classes do not make use of multiple inheritance, thus keeping the class hierarchy quite simple - this makes debugging a somewhat less awful task.

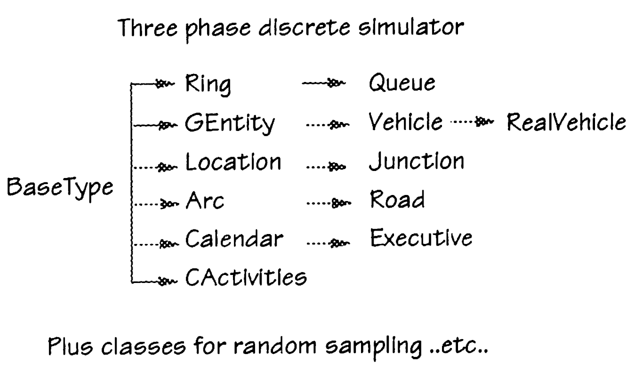

Figure 2: Basic simulation class hierarchy

Though the prototype of CEMPS runs on a SUN SPARCStation, much of the development work on the simulator was done on a PC. This is because the development environments provided by Borland and MicroSoft are much better than those on the SUN, especially for debugging. For the CEMPS simulator, the development work used the Borland Turbo C++ v3.0 compiler and the usual conditional compilation facilities of C and C++ allow re-compilation on the SUN.

6 THE CURRENT STATE OF CEMPS

At the time of writing, CEMPS works but in a limited way. It copes well with rectangular grid-type road networks and there is no reason to assume that it should not work on non rectangular systems, but time has not been available to test this out. The prototype runs rather slowly, mainly due the inter-process communication with the GIS which was mentioned earlier.

CEMPS is now being discussed with various people who are responsible, in different ways, for evacuation planning in the UK. We are endeavouring to understand from them how far the tools need to be developed to take them from a prototype into something which is usable by the planners.

7 POSSIBLE REFINEMENTS TO CEMPS

Various refinements to the simulator are possible and can easily be made. The first is that the time of a vehicle to traverse a road sector is currently independent of the congestion on the arc of the road network being traversed. It is clearly a simple matter to relate the move time through the sector to the loading on the arc. Similarly, the time taken for a vehicle to traverse a road sector in a junction will depend on a range of factors and the model needs to be enhanced to take account of these.

Other possible enhancements are to do with the ways in which vehicles move off after being stopped due to traffic control - the later vehicles in the convoy are delayed as the convoy stretches out. This too could easily be added to the model, but may not be necessary for the scale of accuracy needed for this type of model.

Finally, because the simulator is written in an object oriented style, it is simple to upgrade various classes to make its running more efficient. For example, the list processing of the event calendar is not particularly efficient at the time of writing. It is relatively straightforward to define a descendent class which uses much more efficient processing based on approaches such as heapsort (Knuth 1973. This produces a simulation executive which is suitable for applications with very large numbers of entities.

However, the main area of improvement in order to make the overall system usable is to find better ways to manage the periodic communication with the GIS in its role as display module. Most of the time, the simulator is waiting for the GIS to act, rather than the other way round.

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