MOBEDIC - A Decision Modelling Tool For Emergency Situations

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Contents

Abstract

This paper describes a software tool that we have developed at AIAI for modelling the decisions that people make in emergency situations in offshore environments. The tool was developed using C++ and runs on a PC under MS Windows. It has a generic architecture and can be easily extended to other environments with different characteristics, e.g., hospitals, commercial buildings, etc. We use frames to represent a person's characteristics and their perception of the environment; scripts are used to define typical behaviours for particular situations. Our tool can be used to predict the likely behaviours of a population in hazardous situations and help evaluate the effectiveness of emergency procedures and training.

We have worked with our collaborators to integrate our decision model with their model of people's movement to produce a system that can realistically simulate emergency scenarios on offshore structures. We believe that this is the first egress and evacuation modelling tool to incorporate both decision making and movement modelling. Our work is therefore an important step in the introduction of improved approaches to the evaluation of offshore safety management.

Validating the decision model proved difficult because of lack of suitable data. We acquired additional data by interviewing offshore personnel and monitoring a mustering exercise. We then simulated an offshore emergency scenario and the results were encouraging. In the future we would like to enhance our model by incorporating communication between personnel. This would allow us to model complex scenarios, especially those that cannot be simulated realistically in training exercises.

1 Introduction

A number of recent incidents on offshore installations have increased the awareness of the need to model the evacuation of personnel as part of the evaluation of offshore safety management. Most evacuation simulation tools, e.g., EXITT [9], BFIRES-II [15] & EVACNET [11], focus on modelling peoples movement along various floor layouts. Initial wait times, times for accomplishing specific tasks and some pre-programmed responses to specific stimuli have been incorporated, but peoples decision making has not been modelled. However, the decisions that people make immediately after the occurrence of an incident and subsequently as the environment changes have a huge impact on any evacuation. This is particularly true on an offshore installation, where personnel are well trained and many have unique duties to carry out in an emergency.

It is often assumed that people panic in emergency situations, that their subsequent behaviour is irrational, and that modelling decision making is too difficult or simply not worthwhile. However, studies of human behaviour have shown [14] that people do not panic. It is their perception of the environment, which is often based on lack of knowledge, and conflicting priorities that can lead to behaviour that appears irrational.

We have collaborated with expert psychologists and developed a model of decision making for emergency situations in offshore environments. The model is based on a combination of frames [10] and scripts [13]. Frames are used to represent a person's characteristics and their perception of the environment. This perception is continuously being modified as new information about the environment is received. Scripts are used to define goals for particular situations and the high level actions required to carry out these goals. This model can be easily extended to other environments with different characteristics, e.g., hospitals, commercial buildings, etc.

This paper describes the decision making model and the software support tool MOBEDIC (Modelling Behavioural Decisions In Computer), which was developed using C++ and runs on a PC under MS Windows. We also describe how MOBEDIC has been integrated with our collaborators' model of peoples' movement to produce a system, EGRESS [5], that can realistically simulate emergency scenarios on offshore structures. EGRESS can be used as part of an overall safety assessment methodology for offshore installations [4], to help in the evaluation of platform layout, facilities and emergency procedures. Finally, we discuss the difficulties involved in, and our approach to, validating MOBEDIC.

2 Modelling Decisions in Emergency Situations

This section discusses decision modelling in emergency situations in offshore environments. Firstly, the characteristics of the offshore environment that are relevant to decision making are discussed, then the decision model is described is detail.

2.1 The Offshore Environment

Emergency situations on offshore installations are quite different from that of a shopping mall or underground railway station. The environment is physically isolated from the shore, the crew work and live on the same installation and can be engaged in a variety of activities including eating, sleeping and manual work. Groups exist by the vary nature of the working environment, e.g., the drilling crew work in close proximity to each other and in many cases may be employed by the same contractor. Strong group bonds exist among the crew though it may not always be apparent or may only become apparent in extreme situations.

There is a well-defined leadership hierarchy on an offshore installation, which plays a very important role in emergency situations, as was evident from the Piper Alpha disaster [3]. This hierarchy is complex and offshore personnel only form part of a structure that extends to the shore and other installations. The OIM is in overall command of the installation and is kept informed of events by the Control Room and the Radio Officer who is in constant communication with the outside world. The OIM overseas Emergency Response Teams, First Aid Teams, Muster Captains etc., all who have specific well defined roles to play. Emergency procedures and training give guidelines on how to carry out these roles in emergency situations. Even personnel who do not have special roles receive training and have procedures for emergency situations.

A complete decision making model for the offshore environment should consider all of the above factors. However, the scope of this project did not include modelling the decisions of the OIM or scenarios where the chain of command was broken.

2.2 The Decision Model

It is very difficult to predict accurately just what an individual person will do in a specific hazardous situation. There may be number of options available and there are a number of characteristics of the person and the environment that can influence the eventual decision made. However, it is possible to determine the likely influences that these characteristics will have on decision making. In particular a person's current activity, experience and knowledge of the domain, perception of the environment and training will largely determine what the course of actions will be.

In the field of cognitive science much research has been done in modelling the human thought processes. The more relevant examples include mental models [7], frames [10], scripts [13], schemas [1] and models of decision making [6]. More recent work includes that of Kaemph [8] who has developed a Recognition Primed Decision model of how experts make decisions in emergency situations. The model used in MOBEDIC incorporates both frames and scripts. Figure 1 shows a representation of the model as a KADS [12] inference structure. A frame represents knowledge of a person's characteristics and perception of a situation. This knowledge is continually being modified as a situation progresses. A script defines a goal for a person in a particular situation and the high level actions required to carry out this goal.

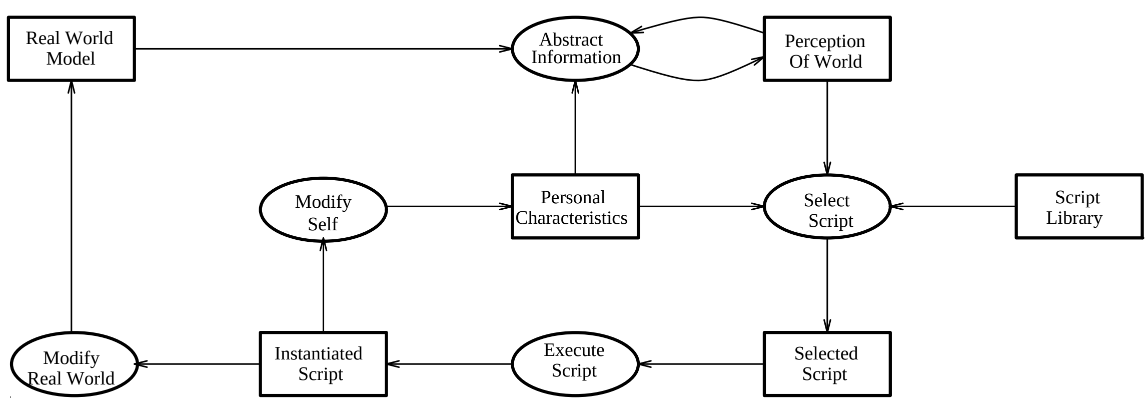

Figure 1: Abstract Model of Decision Making Process

The decision making process can be viewed as a cone, see Figure 2. In any given situation there may be a large number of possible goals that a person can choose. However, some goals may be deemed inappropriate or undesirable and others may be physically impossible to carry out. The underlying principle is to eliminate impossible and/or unlikely goals before selecting the most probable one from those remaining. The same principle is applied where there may be a number of possible sets of actions for carying out the selected goal and also when there is more than one possible way of carrying out an action. For example, if an action involves finding a route to a specific location, improbable routes are eliminated before selecting the most likely one from the set of possible ones. The following sections describe the components of the decision model in more detail.

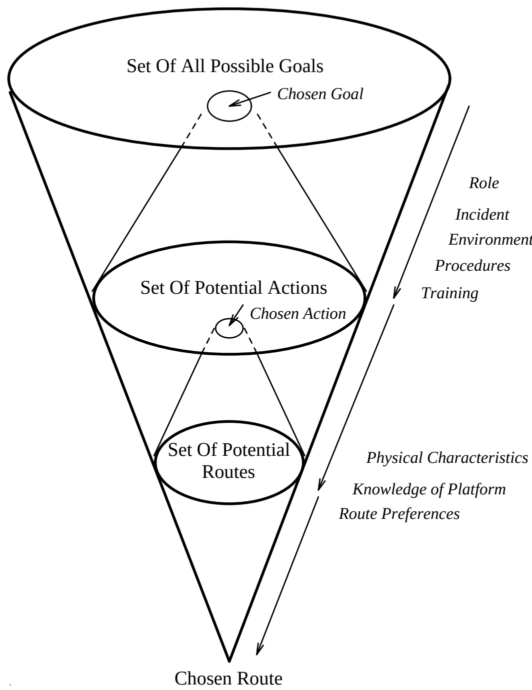

Figure 2: Selection Of Goals/Actions

2.3 The Real World

The Real World represents the environment within which a person exists and interacts. A person constantly receives information about this environment and also has the ability to modify it. Accurate and timely information is critical to a person's perception of the incident and in deciding what actions to take. The content and medium determine the information's ambiguity and directivenes. Ambiguity can influence a person's goals or actions, e.g., it may cause a person to ignore the information or to investigate further. It also influences response times; unambiguous information about the existence of a hazard will provoke faster response times than information which is not completely understood. For example, a PA announcement broadcast immediately after an audible alarm will confirm it's status and personnel usually wait to hear the announcement before responding. A directive message has information which is designed to direct the action of the people concerned. This is also an important factor in influencing response times; a directive message instructing personnel to muster is likely to have a more positive response than one simply informing them that an incident has occurred.

Acquisition of information can be indirect and quite complex. Indirect personal contact, e.g., arm movements, observance of other people's behaviour, unfamiliar sounds, etc., are important in communicating information about an incident. Cues like these can confirm or otherwise the seriousness of a situation. Cues can have a cumulative effect and a series of ambiguous cues can have the same effect as a single unambiguous cue.

2.4 Abstracting Information

Information from the real world is abstracted and used to modify the person's perception of this word. The process of abstracting information is dependent on a person's current knowledge of the environment and on their personal characteristics. A person's current knowledge results in an expectation about what happens in the world and whether new information constitutes a significant change in this expectation, e.g., the presence of smoke is something which would be unexpected in a normal workplace. A person's characteristics, such as current activity, would also influence the relevance of a cue, e.g., a person already enroute to a muster point would ignore further alarm bells.

2.5 Perception Of World

A person's perception of the world is one of the most important factors that influences decision making. This knowledge includes beliefs such as: the likelihood that a hazardous event has actually occurred; the location of the hazard; the type of hazard; the degree of threat to the integrity of the installation; the degree of threat to the person's own life and the degree of threat to other people's lives. Perception is not simply dependent upon new information being received but also upon existing knowledge, e.g. how different types of hazards escalate, emergency routes and layout of the installation. Different people will therefore have different perceptions of the same "real world", e.g., the duties of the catering stewards are usually confined to the accommodation module and in general they are only vaguely familiar with other areas of the installation. Training exercises play a very important part in familiarising the crew with the layout of the platform and the risks posed by specific hazards.

2.6 Personal Characteristics

As a result of knowledge elicitation with expert psychologists and interviews with offshore personnel a number of factors that influence decision making in emergency situations were identified. For emergency situations on offshore installations, we believe that the following characteristics are the most important to model.

Role/Training This effectively defines a body of procedures that should be followed in specific situations. Of course, in extreme situations procedures may not be adhered to and the chain of command may be broken. However, even in these situations a person's training can be used as a basis for predicting the most likely decisions that a person may make.

Ongoing activity This is a very important consideration in deciding how long a person will take to make a decision and what that decision will be. There is a strong desire to finish the current task or at least to continue with it. The strength of this desire is dependent on the commitment to the task involved, e.g., a person engaged in manual work will tend to respond more slowly than someone who is engaged in a leisure activity.

Mobility This will influence a person's ability to move and hence any decisions that would be made. In general, the crew on offshore installations are fit and healthy, though injuries of varying severity may occur during an incident.

2.7 Scripts

A library of scripts is used to define peoples' goals and actions for specific situations. A script is a structure that describes a stereotyped sequence of events for a particular context. The important components are the *header* and the *body*. The header represents the "entry conditions", i.e. those conditions that must be met before the events described in the body of the script can occur. These conditions usually, though not necessarily always, relate to a person's characteristics and their perception of the world. The body of a script describes the relevant goals for and the high-level actions required to carry out the goals.

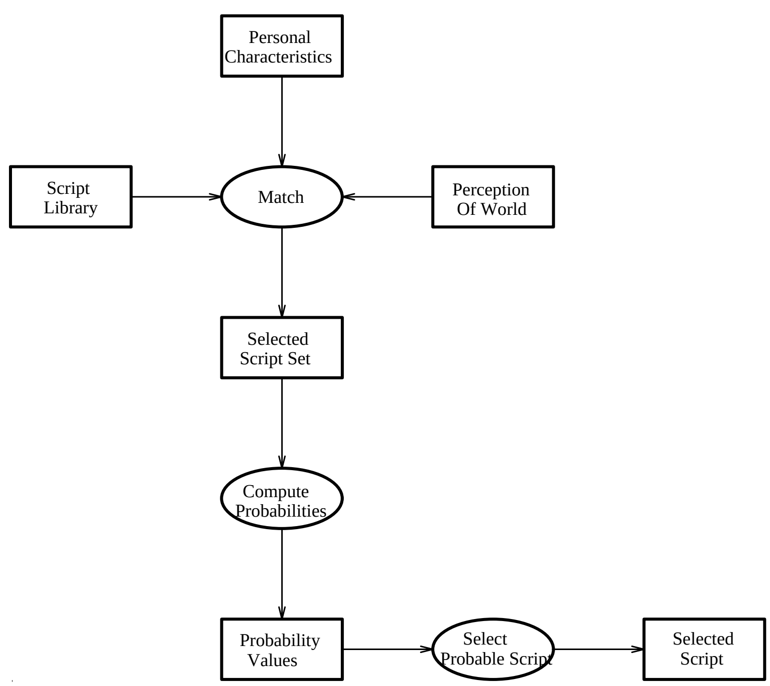

Figure 3: Abstract Model of Script Selection Process

We have adapted the script notation for our model and included the concept of a script set. Each script in a set has the same header; a set of scripts therefore applies to a specific situation or scenario. Each member of a set has a probability rating that determines the probability of this script being selected from the set. In this manner the non-deterministic behaviour of people can be modelled. When a person's perception of the world has changed it may result in a new script being selected, i.e. a new decision being made. Figure 3 shows a KADS inference model of the script selection process.

The personal characteristics and perception of the environment for a decision making group are compared with the headers of all possible script sets in the script library. When a matching script set is found a script is selected based on its probability value. The goals defined in the body are instantiated for the relevant decision making group and the actions required to carry out the goals are executed. The selected script may modify a person's characteristics, e.g., ongoing activity, or can modify the real world. Modifying the world can result in new information being received and the decision making cycle starting again.

3 The EGRESS Computer Tool

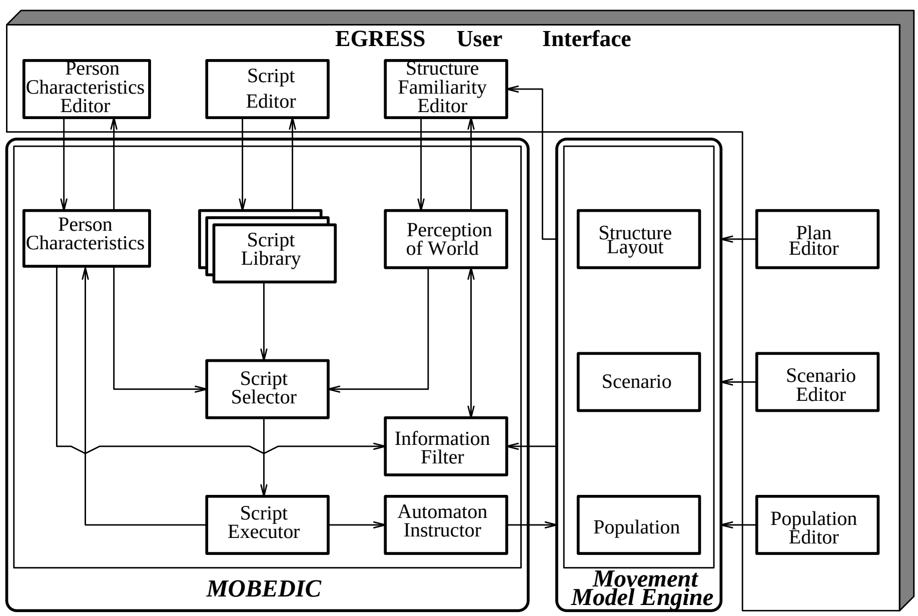

Figure 4: The EGRESS Tool Architecture

This section describes the EGRESS tool which consists of the integration of MOBEDIC and a Movement Model, see Figure 4 for a conceptual view of the EGRESS architecture. The two models have been designed and implemented separately but they share the same User Interface (UI). This section contains a brief overview of the Movement Model and a more detailed description of MOBEDIC.

3.1 Movement Model

The Movement Model represents the physical structure of the offshore installation using a hexagonal cellular grid, see Figure 5. [1] A *Plan Editor* allows the user to define physical structures, such as walls, equipment, etc., using different types of cells. Attributes can be assigned to cells to include additional information about the plan, e.g., the degree of lighting.

The Movement Model also represents information about the hazardous incident. A *Scenario Editor* allows the user to specify the hazard, its escalation and effects on the structure over time. For example, the location of and intensity of smoke can be specified at a number of time steps.

Personnel are represented using *cellular automata*, which can move about the plan from cell to cell. The automata are created using a *Population Editor*. An individual automaton cannot, of course, occupy cells representing walls, etc., or cells occupied by other automata. The movement and interaction of the automata on the cellular grid simulate the movement and physical interaction of people on a platform. More detailed information about the Movement Model is contained in [5].

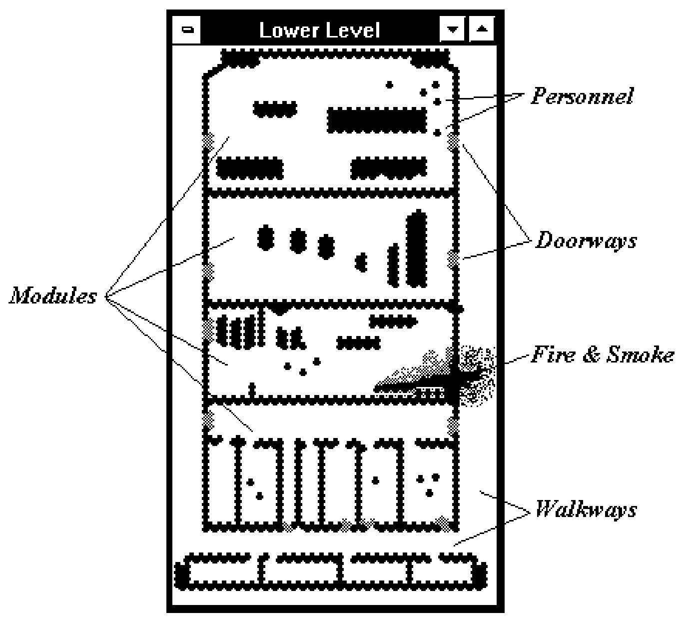

Figure 5: Example EGRESS Floor Plan

3.2 MOBEDIC

MOBEDIC represents the "brain" of the automata in the Movement Model. It explicitly models decision making knowledge using scripts and frames and can respond to a changing environment and instruct automata to carry out specific actions. The basic Decision

[1] This is a screendump that has been annotated with text

Making entity in MOBEDIC is the *Group*. A Group is a collection of one or more members with a single *Decision Making Leader (DML)*. Effectively the DML is the group; it is a notional leader and does not represent any individual. The DML receives all communications and makes all of the decisions relevant to a group. The final decision made by the DML is issued to the group members as an itinerary of actions. Ordinary group members do not possess any knowledge at all. They simply translate the itinerary of actions, specified by the DML, into instructions for the equivalent automaton in the Movement Model. The DML is informed of the progress of each member. [2]

Groups can be of arbitrary size and it is possible to represent an individual, e.g., the Safety Officer or the entire population as a single group. In MOBEDIC group members should occupy the same location or be in close proximity to each other at the initiation of a hazard. In addition, they should have the same role and have the same destination, e.g., same muster point. Currently groups do not have the ability to split up and re-form, which can happen in emergency situations.

3.3 Personal Characteristics

The personal characteristics that have been described earlier are represented as slots in the frame of the DML for each group. These slots can be modified during the course of a simulation.

3.4 Perception Of World

Humans have very complex models of the real world and expectations about the type of events that can occur. However, a much simplified model of the environment is considered here that includes knowledge of the layout of the platform, location of muster points, the location and extent of any hazards. Figure 6 shows a schematic floor plan with modules, doors, corners and stairs. Doors, stairs and corners are represented in the Movement Model using *Regions*. These regions have associated attributes or information attached to them, which is used by MOBEDIC. These regions correspond to *information points* and form the basis of the representation of the environment in MOBEDIC.

3.4.1 Information Points

Information points have the following characteristics:

Waypoint This is an attribute introduced because of the way that the Movement Model works. Personnel (or automata) can only move to specific regions, i.e. waypoints, though they can traverse any region. Waypoints are used therefore to represent structural information, such as doors and stairs. Smoke, e.g., would not be a waypoint, though a person may know where it is and can travel through it.

[2]Representing the knowledge of and simulating the decision making processes of each individual on a platform, which could be about 200 people, would make significant demands on computer memory and run time speed. It is also unnecessary. Eventhough the population is composed of individual autonomous people, group formation is an important feature of their behaviour and it is possible to divide the population into various groups.

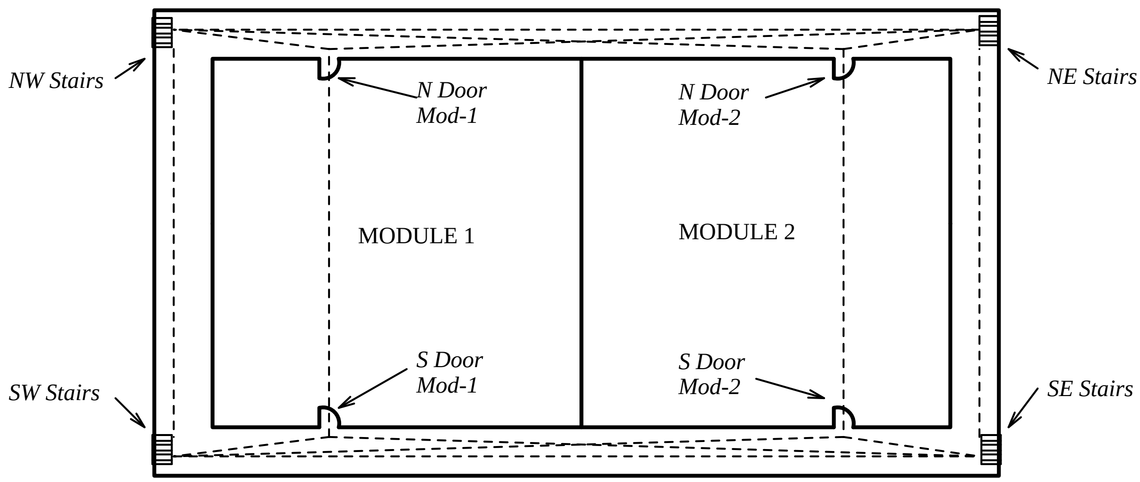

Figure 6: Sketch of a Floor Plan

Lighting This is an indication of how well lit the region is and can influence perception of the environemnt and route selection.

Proximity to event This is an indication of how close a region is to a hazard. Regions that are very close to a hazard are usually avoided during egress, provided that personnel are aware of the hazard's location.

External/internal This indicates whether the region is located inside a module or outside. During emergencies personnel are advised to exit modules and take external routes to their muster points.

Wind direction This is an indication of whether the region is upwind or downwind of the hazard, e.g., routes that are downwind may be preferred in the event of a gas leak.

Sign system Some routes may be marked better than others (e.g., with "Emergency Exit" in neon lights) and would offer valuable clues to anyone trying to find their way.

In addition to the above information each group will have an associated degree of *familiarity* with a region, indicating their familiarity with the installation.

3.4.2 Hazards/Incident

Hazards, such as smoke, fire and gas are also represented as specialised information points; the information in this case concerns the type of hazard. An incident can therefore be considered as an extension or modification of the characteristics of the environment.

3.4.3 Routes

A route consists of a sequence of route segments. A route segment defines the shortest travel distance between two waypoints that does not include any other waypoints. However, a segment may contain other information points, e.g., hazards. The characteristics of a route are determined by the characteristics of its constituent segments, which are evaluated by considering the waypoints and other intervening information points on its path. Routes will have the following characteristics in addition to those defined by information points.

Travel length This is the travel distance between two points. The geometry of a route may be complex and this is evaluated by the Movement Model.

Complexity This is an indication of how difficult it is to negotiate the route. This factor is influenced by the number of waypoints and the geometry of the plan between waypoints.

Availability This is determined by the presence of hazards enroute, defined in turn by the presence of hazard information points. Fire, dense smoke and gas effectively make a route unavailable. However, using special equipment, e.g., a breathing apparatus, enables personnel to move through dense smoke and gas. Availability, is therefore an attribute that is dependent on the person in question.

3.5 Information Filter

The Movement Model broadcasts information about the environment to MOBEDIC. This information consists of an automaton's progress through the plan and any modifications to the environment. The relevance of this information is determined by a person's knowledge and personal characteristics. New information can result in the modification of a person's perception of the environment and a new decision being made, i.e. a script being selected. The representation and selection of scripts is described in the following section.

3.6 Representation Of Scripts

Figure 7 shows an example of a script as it would be displayed to the user of the system. A script has a unique *name* which is used for identification purposes only. A script also has *conditions*, which consist of attributes and constraints on its values. These attributes can relate to the person's perception of the environment or to personal characteristics, e.g., role. When the constraints on each condition's attributes are satisfied the script is eligible for selection. The body of a script consists of *actions*. Actions can be of two types: they can set goals, such as "Go to muster point", or they can modify the value of a personal attribute, e.g. mobility. This representation is a natural formalism and it is easy to relate inputs for the decision model to conditions in scripts. It can be easily modified by the safety analyst to reflect different roles, conditions or procedures.

Scripts are arranged into *script sets*. A script set contains a number of scripts whose conditions are the same. A script set has a *priority value* which determines the relative

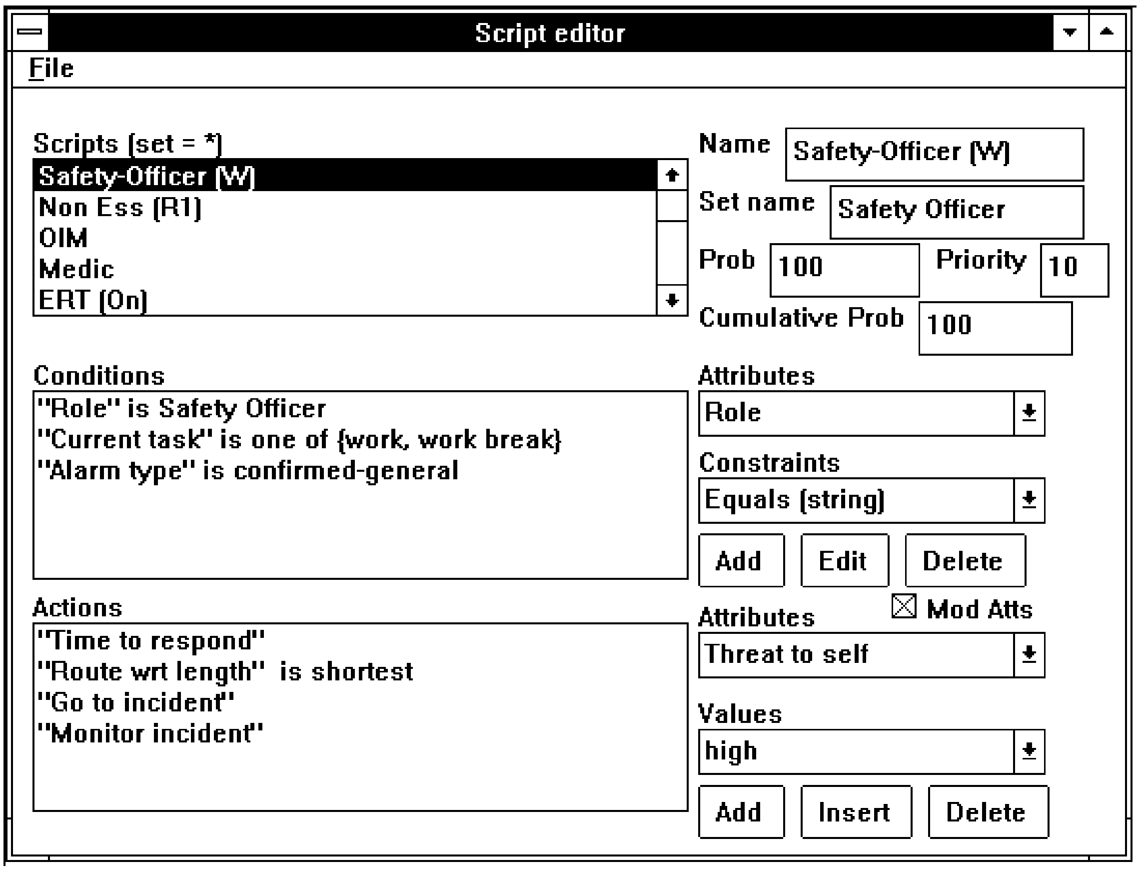

Figure 7: Example Script

importance of the set. In a given situation there may be more than one script set that is applicable and the one with the higher priority is chosen. Each script in a script set has an associated *probability* value, which is less than 100. The sum of the probability values for all scripts in a set is 100. This attribute of a script allows script selection to be non-deterministic and scripts within a set are selected by random, but weighted by the value of the probability factor. This attribute is very important in circumstances where it is difficult or impossible to predict the decisions that a group will make. Also, in certain circumstances groups which may have the same role and training may make different decisions.

3.7 Script Executor

When a script has been selected the actions are interpreted and the results added to the person's *agenda* of actions. Actions can modify personal characteristics or set goals which result in moving to a specific location, e.g., mustering. Modifying personal characteristics is quite a trivial exercise and simply involves updating the value of the relevant slot in the frame. However, an instruction to go to a specific location is more complex and involves finding a suitable route.

Finding a route involves performing a beam search of the tree of possible routes, see Figure 8 which shows a partial expansion of routes from the NW stairs to the SE stairs. The characteristics of the route segments and the evolving partial route are used to prune the search space of all possible routes, which can be huge in complex plans such as offshore structures. The priorities of these characteristics are dependant on the person involved, e.g., "non-essential" member of the crew will regard the hazardous characteristics of a route differently than a member of the fire team wearing a breathing apparatus. When a route is selected the waypoints that comprise it are stored on an agenda of places to visit.

3.8 Automaton Instructor

The automaton instructor pops regions off the agenda, and sends them to the Movement Model with instructions to move or wait, as the case may be. The Movement Model is constantly sending information to MOBEDIC that includes the progress of automata along their specified routes. When one instruction is complete another one is popped off the agenda and sent to the Movement Model, unless of course another decision is made in the meantime and the agenda is modified.

3.9 Editors

There are three editors provided by MOBEDIC, which allow the user to define the decision making knowledge and to view the decisions that have been made.

Script Editor This allows the user to create and browse through a library of scripts which are relevant for a simulation, see Figure 7. The script editor provides a pseudo-English interface to the scripts which makes them easy to edit and understand.

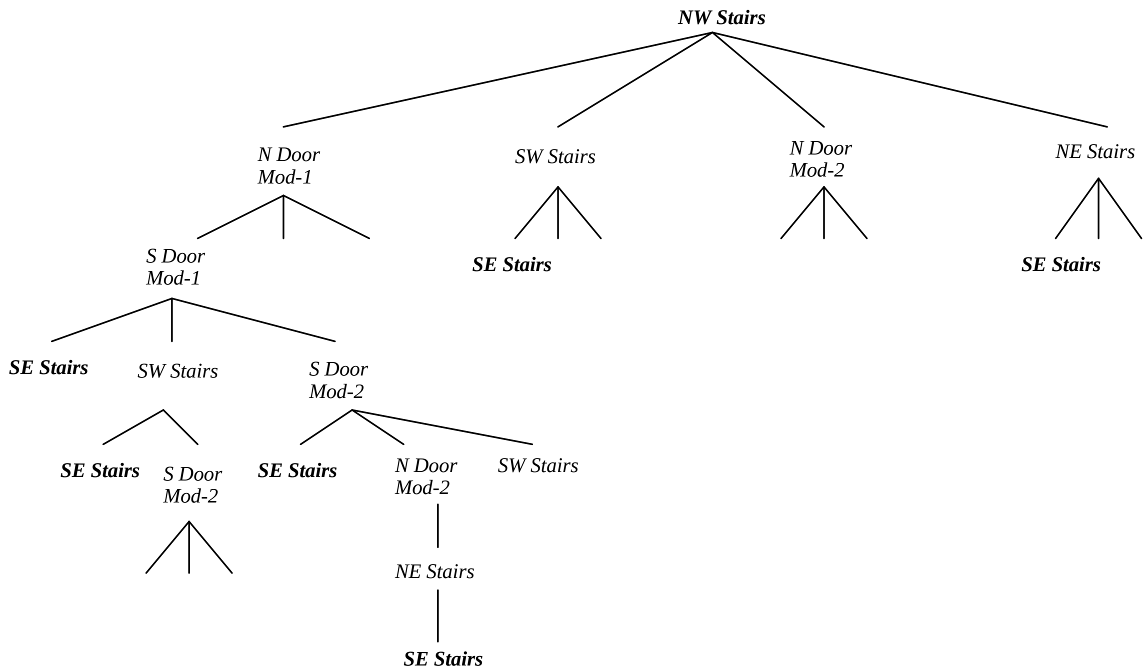

Figure 8: Expansion Of Routes

Personal Characteristics Editor This consists of two parts, the *Decision Model Editor* and the *Action Agenda*, see Figure 9. The Decision Model Editor allows the user to define the characteristics of personnel e.g., emergency role and current activity. In this manner a population can be specified which reflects the different duties and characteristics of personnel on board an offshore installation. The Action Agenda displays information about decisions made and actions planned or already executed.

Familiarity Editor This is a simple "dialog box" that allows the user to specify a person's level of familiarity with various parts of the structure. Different people will be familiar with different parts of the structure, depending on their day to day duties and training, and this familiarity is critical when choosing exits and routes.

4 Validating MOBEDIC

Validating a tool like MOBEDIC is made difficult by the lack of relevant data and the difficulties in interpreting this data. A literature review carried out at the start of the project revealed that some data exist on evacuations of public buildings and shopping malls [2]. However, these data are of limited use for the offshore environment. Our approach was to supplement existing data by interviewing offshore personnel and by monitoring a mustering exercise on an offshore installation. Interviewing personnel is not a reliable method for acquiring detailed information about behaviour in hazardous

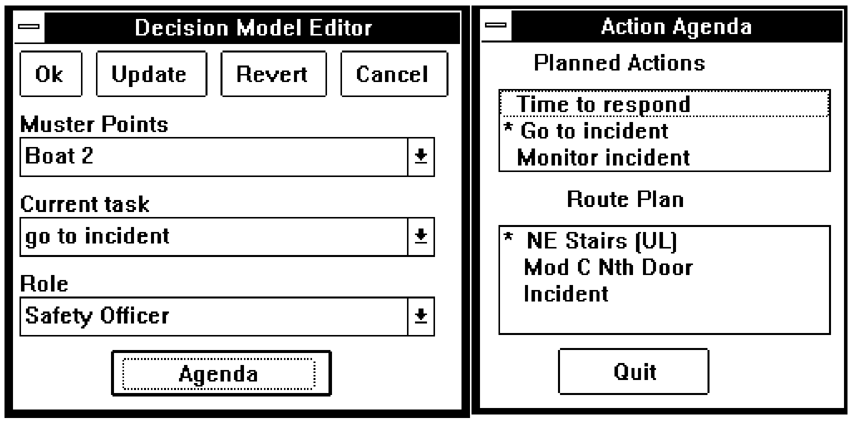

Figure 9: The Personnel Editor

situations; however, it proved useful for acquiring information about safety procedures, staff training and general behaviour patterns of personnel in previous incidents.

4.1 The Mustering Exercise

The mustering exercise was carried out on Texaco's Tartan Alpha platform during February 1993. The exercise simulated a torch fire in one of the production modules, which eventually resulted in part of the platform becoming untenable. It was intended that the planned exercise would be an extension of one of the weekly exercises. Personnel were informed about the exercise and its objectives. However, in order to make the exercise more realistic the following changes were made:

1. personnel were not told the exact time of the exercise and would therefore be carrying out their normal duties and would have to respond in a similar way as to a real incident, e.g., wake up, make work safe, etc.;

2. personnel were not told what kind of scenario would be simulated and would not know about potential route blockages.

The scene of the incident and muster points were monitored by seven "participants". Routes and mustering times were recorded for every person. Travel times were deduced for personnel whose exact location at time of alarm and exact route to muster point were known. In addition only those personnel who took relatively uncomplicated routes were chosen for calculations since it would have been difficult to accurately deduce travel times for complex routes. Response time were then calculated using travel and mustering times. Accurate data on response and travel times were obtained for 30 % of the population that included a representative distribution of emergency roles, pre-exercise activities and pre-exercise locations. These data were then extrapolated to the rest of the platform population.

4.2 Modelling a Scenario

The "incident" was simulated using the combined decision making and movement models. A plan of the offshore platform was created representing the layout of all cabins, modules, walkways, stairways, machinery, etc. All personnel were modelled, including those who were on-scene when the incident occurred. Initial location, current activities, emergency duties and muster points were specified for each person. The behaviour of personnel were analysed using the following criteria:

1. times to respond to the initial alarm;
2. routes selected;
3. decisions made on encountering the "hazard" enroute;
4. influence of the tannoy messages from the Control Room concerning the status of incident, the module and external walkway.

The results of the simulation were encouraging. Personnel reacted differently depending on their individual characteristics and the environment, and their overall behaviour was similar to what would be expected in a real situation. Those personnel at the scene of the incident activated the alarm upon observing the incident and then proceeded to muster. Personnel did respond to alarms and their response times varied with their activities. Routes selected reflected what were taken in the exercise; personnel chose familiar routes, avoided crossing production modules and took external walkways where possible. Personnel who encountered the "incident" enroute to their muster points were forced to find alternative routes. Upon hearing the tannoy message from the Control Room concerning the status of the incident, those personnel who planned to use the blocked walkway changed route and avoided the incident.

4.3 Discussion

We are not interpreting these results as a complete validation of our tool; this will require gathering much more data and simulating a greater number of different scenarios. In addition, there are inadequacies in using exercises of this type to gather data:

1. personnel are (and indeed must be) told of the exercise and will be mentally prepared for it;
2. there will be no direct observance of gas, smoke or fire as there would be for a real incident;
3. there will not be any real urgency in actions;

4. there will not be any real uncertainties about threat to life or to the platform.

However, exercises like these can yield very useful information. The data, when combined with other data obtained from interviews, on-shore observations, and combined with a model of human decision making can give a very useful insight into peoples' behaviour in emergency situations.

5 Concluding Remarks

MOBEDIC demonstrates that it is possible to model the behaviour of people in hazardous situations. The results of simulations, while they cannot be interpreted as validation of the model, are very encouraging. The combined EGRESS system can simulate scenarios in different platform layouts and help in the design of safer installations or in the improvement of existing ones.

The explicit representation of personnel, their characteristics and scripts makes it very easy to input information and to visualise the results of the simulation as it is being executed. Scripts can be easily created and/or tailored for different environments and populations using the graphical editor. Varying scripts within a particular domain allow us to evaluate the effectiveness of existing procedures and to identify how training can be improved.

The nature of the domain makes it very difficult to obtain reliable data with which to validate the model. Validation, is also complicated by the fact that it is impossible to predict, even using a very detailed model of human reasoning, what exactly will happen in a given situation. The characteristics of the crew differ from shift to shift, from installation to installation and can even vary over time within the same population. However, by carrying out a number of simulations with different population profiles, MOBEDIC can be used to predict the likely behaviours of a population in a hazardous situation.

In the future, we would like to extend MOBEDIC by modelling communication between personnel. Communication involves sharing and comparing information between the frames of decision making entities. Modelling communication would allow us to model complex scenarios, e.g., where there is significant structural damage; scenarios where there are casualties; and scenarios that cannot be simulated realistically in exercises.

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