Bushfire CRC
Enhancing Safety
Project (D2.3)

Report Number 2:2004

Development of Computer Simulated Wildfire Scenarios for the Experimental Investigation of Unsafe Decision Making

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Copies of this report are available from Mary Bertoldi, Bushfire CRC, La Trobe University: m.bertoldi@latrobe.edu.au.

The latest version of Networked Fire Chief, together with base scenarios described in this report, is available from Matt Walshe, Complex Decision Research Group, La Trobe University: m.walshe@latrobe.edu.au.

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Summary

- We provide a brief overview of the two complementary research methods we propose to use to identify human factors which lead firefighters to make unsafe decisions, namely: (a) Interviews specifically designed to reveal underlying psychological experiences and processes, and (b) Experimentation using computer-simulated scenarios specifically designed to elicit the relevant psychological experiences and processes. The present report, Report 2:2004, focuses on the development of experimental scenarios, a companion report, Report 1:2004, focuses on the development of a suitable interview protocol.

- We present a case for the use of computer simulated wildland firefighting scenarios (rather than only relying on field exercises, prescribed burns, and naturally-occurring incidents), for the targeted investigation of underlying causes of unsafe decisions in the context of wildland firefighting.

- We outline a set of requirements for a computer-based wildland firefighting simulation tool to be adequate for the systematic investigation of human factors underlying safety-compromising decisions. In introducing these requirements, we draw particular attention to: (a) the need to distinguish between the concepts of physical and psychological fidelity in simulation design; and (b) the relative importance of each type of fidelity for investigating human decision making.

- We introduce Networked Fire Chief (Omodei, Taranto, & Wearing, 2003) as a proven research tool for meeting the identified requirements. Networked Fire Chief is a wildland fire fighting scenario generator specifically designed for research into psychological processes involved in decision making under conditions of complexity, time-constraint, risk, and uncertainty. We describe the Networked Fire Chief program, summarise the program's main features and editors, and provide evidence of the program's suitability for research into the psychological processes involved in decision making.

- In order to determine possible availability of alternative wildland firefighting simulators suitable for targeted investigation of unsafe decision making in wildland firefighting contexts, we present a review (according to the abovementioned requirements) of seven wildland firefighting simulation programs we were able to locate. We conclude that of these seven programs, Networked Fire Chief is the best, and most cost-effective, tool currently available to enable the proposed research to be undertaken in the time frame required.

- In our review of the alternative simulation programs, however, we note two simulators currently under development that might prove suitable for the psychological investigation of unsafe decision making, namely 3D Fire Sims and VectorCommand Wildfire (IMT). As these programs become available, we will examine them for their suitability to complement the research activity initiated using Networked Fire Chief.

- We briefly outline an overall research strategy for using Networked Fire Chief to generate test scenarios of maximum sensitivity, including close involvement of fire agency personnel, and close attention to emerging research findings (both within, and external to, the Bushfire CRC).

- We describe several programming extensions implemented as part of the "Enhancing Safety" Bushfire CRC project to increase the suitability of Networked Fire Chief generated scenarios for use with firefighters familiar with wildland fire behaviour and fire suppression strategies.

- We then present a suite of base landscape scenarios that we created using Networked Fire Chief to be evaluated for suitability for the presentation of safety threats during experiments. In selecting landscape areas for these base scenarios we drew upon four complementary sources: (a) actual areas in which safety-compromising incidents had been reported; (b) actual areas currently in use for field simulation training and assessment, (c) areas specially created for use in wildland firefighter training programs, and (d) areas specially created by us for the targeted investigation of proposed decision making errors.

Recommendations
The following are recommendations for research activity in subsequent phases of the D2.3 Bushfire CRC project.

- The development and testing of Networked Fire Chief generated scenarios be continued, with input from Fire Agency personnel with expertise in wildfire behaviour, wildfire suppression strategies, and firefighter health and safety.

- When 3D Fire Sims and/or VectorCommand Wildfire (IMT) become available, we recommend that these programs be investigated for their suitability to create experimental safety relevant wildfire scenarios. Close attention could also be paid to the proposed work in project A5.1 (Bushfire Spread Simulation and Modelling) as this may also generate a tool suitable for the generation of safety-relevant scenario. Should the attributes of any of these programs be found to complement those of Networked Fire Chief we would recommend that multiple computer platforms be used to research the relevant safety factors to allow validation of findings across diverse research simulation platforms.

- Wherever feasible, the specific findings and conclusions obtained from experimentation with computer-simulated wildfire scenarios should be subsequently tested in (a) field simulation exercises and (b) prescribed burns.

- Existing incident investigation reports should be re-examined for evidence relating to the specific findings obtained in experimentation using computer-simulated wildfire scenarios.

Notes

1. *We invite persons in End User Fire Agencies provide suggestions as to how we might best implement such research activity.*
2. *Input from our research colleagues in other Bushfire CRC Programs would also be most welcome, particularly those whose own work has implications for our selection and use of computer-simulated safety scenarios. Such work includes, but is not necessarily restricted to: (a) advances in understanding of fire behaviour, (b) programming techniques for modelling such fire behaviour, (c) and programming techniques for the dimensional rendering of landscape terrain.*

1 Background

The overall aims of the 7-year D2.3 “Enhancing Safety” project are to (a) identify the “human factors” that lead Australian wildland fire fighters to make decisions that place themselves or others at risk, so as to (b) produce guidelines and recommendation for training and operations which will reduce the negative impact of the identified human factors on firefighter safety.

For the purposes of this overall project we use the term “human factors” to refer to those factors which influence how the human mind operates (note that other CRC projects investigate factors which influence how the human body operates). The D2.3 project, therefore, seeks to identify those factors, whether at the individual, group, or organisational level, which influence human decision making in Australian wildland firefighting contexts. A brief overview of the main classes of human factors is presented in Appendix A.

Two complementary research techniques are used most frequently by researchers to identify and study human factors

1. Interviews specifically designed to reveal underlying psychological experiences and processes, and
2. Experimentation using computer scenarios specifically designed to elicit the relevant psychological experiences and processes

2 A Case for Computer-Simulated Wildfire Scenarios

In this section we outline the case for using computer simulated wildfire scenarios (rather than relying solely on field exercises, prescribed burns, and naturally-occurring incidents) for the safe and controlled investigation of the underlying causes of unsafe decisions in the context of wildfire fighting.

Field simulation exercises, prescribed burns, and naturally-occurring incidents provide valuable information but they are generally unsuitable for the controlled, detailed investigation of the human factors which underlie safety-relevant decisions. Field simulation exercises and prescribed burns rarely offer the levels of safety, flexibility, and experimental control that are required to create conditions that are (a) fully reproducible, (b) of known structure, (c) able to be systematically modified, and (d) allow for the unambiguous determination cause and effect. Computer-based simulations, on the other hand, do allow for such flexibility and tight experimental control over scenario design. Moreover, in those circumstances in which it is possible to develop field simulation exercises which incorporate elements implying specific threats to safety in a controlled manner, this becomes a very costly and time-consuming activity.

Nevertheless, we emphasise the importance of subsequently testing the specific findings from computer simulations in field exercises and prescribed burns and comparing incident investigation reports and human factors reviews with them. It is possible that recommendations for the modification of existing incident investigation procedures and protocols may come from findings obtained with computer simulations.

3 Computer Simulation Requirements Analysis

In this section we develop a set of proposed requirements that a computer-based wildland firefighting simulation tool should meet to generate suitable scenarios for research into safety-relevant decision making.

Raby et al (2000) developed a general methodology for evaluating a simulator's capabilities which we adopted as a basis for developing a list of requirements for evaluating wildland firefighting simulation programs. We thus propose the following six requirement categories:

1. Allows the generation a wide range of potentially safety-relevant scenarios.

2. Replicates weather, landscape fuels, topographic conditions, and implements a plausible fire spread model.

3. Affords opportunities for a full range of fire suppression activities, and incident command, communication, and control structures.

4. Provides full statistical performance data and a full on-screen simulation replay facility.

5. Provides for complete scenario reproducibility across repeated experimental trials and repeated participants and participant teams.

6. Possesses adequate levels of physical and psychological fidelity.

Adopting these six general categories of simulation requirements as a conceptual framework, we developed a more detailed set of requirements for creating safety-relevant experimental scenarios.

Note that in presenting these requirements we use the following terms:

Developer a person who works with the simulator's editing facilities to create/design specific wildfire scenarios.

Facilitator a person who provides scripted or experimenter-determined run-time input and/or control over developments in the simulated scenario as it plays out.

Participant a person whose experiences and behaviour in the simulated scenario is the focus of research interest.

3.1 *Allows for the generation of a wide range of potentially safety-relevant scenarios*

A. The program should be capable of being flexibly and fully networked. As most wildland firefighting takes place in the context of teams (ranging from a single appliance crew to an incident management team), the program should be capable of being flexibly and fully networked enabling a facilitator to allocate participants to teams with separately configurable information displays and firefighting resource availability.

B. The program should be able to vary the information that each *participant* is provided with (or is able to access). Such information should be able to be varied according to amount, level of detail, reliability, and timeliness.

C. The program should allow the scenario *developer* to implement a set of pre-determined events such as fire outbreaks, changes in weather conditions, etc.

D. The program should allow *facilitators* to dynamically introduce new events, or otherwise alter the course of existing events, as the simulation is being run (such as by introducing new fires, announcing the failure of crews to arrive, creating sudden wind changes etc.)

E. Simulation scenarios of adequate complexity and variety should be able to be created by the local *developer.* That is, the local developer should not be restricted to implementing only minor variations on the base scenario(s) that are built into the simulation program itself.

F. Simulation scenarios of any level of complexity should be easily and quickly created and/or modified by the local *developer*.

3.2 Replicates weather, landscape fuels, topographic conditions, and implements a plausible fire spread model

G. The program should afford full *developer* control over the size and composition of the landscape area, including all features typically made available to wildland firefighters from existing topographic maps.

H. The program's landscape editor should accommodate different types of fuel loads and fuel moisture content.

I. The program should be able to re-create urban areas of varying density and a realistic rural/urban interface.

J. The program's fire spread model has to be sufficiently realistic that any deviations from real-world fire behaviour are sufficiently minor as to go unnoticed by the typical *participant*.

K. The program's fire spread model has to able to accommodate a range of fire behaviour (e.g. provision of different spotting characteristics).

3.3 Affords opportunities for a full range of fire suppression activities and command, communication, and control structure

L. The *participant* should be able to continuously interact with the simulated scenario in real time via the user interface (rather than merely via instructions to *facilitators*) so as to engage fire suppression and communications activities.

M. The computer interface by which *participants* interact with the simulated scenario should be as non-intrusive (natural) as possible. The aim is for *participants* to have as close as possible to the same mental experiences they have in real world fire fighting (although obviously they can't have the same physical experiences -- This bears on the issue of simulation fidelity which is discussed further in the following section).

N. Specialist firefighting appliances should be able to be created by the scenario developer to enable the full range of potential fire suppression activities.

O. In order to study the strategic decisions made by participants (e.g., where to construct a control line), the scenario *developer* should have the option of allocating the implementation of this decision (e.g., progressively moving the selected firefighting appliance along the designated control line) to in-built AI (artificial intelligence) routines.

P. *Facilitators* should be able to allocate additional fire suppression resources and to modify the status of existing fire suppression resources as the simulation is being run.

Q. The *developer* should be able to build scenarios that replicate existing command, communication, and control structures and procedures.

3.4 Provides full statistical performance data and a full on-screen simulation replay facility

R. The program should be able to generate detailed output data on participants' overall performance and performance history.

S. The program should have a replay function to support post-incident reviews and analyses.

3.5 Provides for complete scenario reproducibility across repeated trials

T. Each simulation scenario should be reproducible across different *participants* and teams of *participants*.

3.6 Possesses adequate levels of physical and psychological fidelity

To some extent this category of requirement is a more general one, encompassing each of the requirements listed immediately above. The overall aim of the above set of simulation requirements is to place teams of trained wildland fire fighters as research participants in carefully and precisely defined scenarios so that their experiences and their opportunities to exert control over the simulated fires are as similar as possible to those they would typically encounter in actual incidents. These requirements therefore aim to achieve the more general simulation requirement of adequate scenario fidelity. Clearly, there are practical and economic constraints on just how much fidelity can be achieved in a computer simulation. Notwithstanding, because of the central importance of this issue, in this section of the report we provide an extended discussion of scenario fidelity.

To evaluate the overall level of fidelity required and/or achieved in a particular simulated scenario one needs to distinguish between physical and psychological fidelity. As adequate fidelity is of central importance if one is to be able to generalise any findings obtained with simulation scenarios to the real world that these scenarios purport to model, careful attention to aspects of fidelity is of paramount importance. The distinction between the concepts of physical and psychological fidelity and their place in research into safety-relevant decision making is discussed below. (A more comprehensive discussion of simulation fidelity can be found in Elliot, Darlymple, Regian, & Schiflett, 2001; and Omodei & Wearing, 1996).

3.6.1 Physical Fidelity

Physical fidelity refers to the extent to which the simulation is successful in reproducing the physical aspects of the environment. Examples of high physical fidelity in a wildland firefighting simulation would include: (a) the sights, sounds, heat, and smell of a wildfire; (b) the same suppression and communication equipment that is used in wildland firefighting; and (c) simulated fires that behave according to the same laws of physics/chemistry as do actual wildfires (i.e., implementing a completely accurate fire spread model).

3.6.2 *Psychological Fidelity*

Psychological fidelity refers to "the degree to which the simulation captures the functional and cognitive aspects of the performance domain" (Entin et al, 2001). In other words, a wildland firefighting simulation should place the same cognitive demands on participants' decision making and thought processes as occurs in actual wildland firefighting. Psychological fidelity, in the context of creating safety-relevant scenarios, requires scenarios that give *participants* the same decision making experiences that they could be expected to have in real wildfires. This requires scenarios that simulate fire spread and fire suppression behaviour at a level observable by the typical firefighter in the field. That is, the scenario should embody just those principles of fire physics and fire chemistry which, if violated, would be obvious to *participants*. In summary, it is important that scenarios not contradict any laws of nature or operational procedures of which *participants* are likely to be aware.

Although perfect physical fidelity will, in most cases, make it more likely that adequate psychological fidelity is achieved, it is possible to achieve quite high levels of psychological fidelity in the absence of full physical fidelity. For example, what is required for the present research is physical fidelity with respect to features of the decision environment that are important for achieving psychological fidelity of the cognitive kind (i.e., the mental processes and experiences involved in decision making under complexity, time-constraints, risk, and uncertainty). In making tradeoffs in scenario design, adequate psychological fidelity of the decision making kind can often be better achieved by paying attention to those aspects of physical fidelity involved in providing frequent, immediate, and non-intrusive opportunities for participants' to interact with the simulation (i.e, by making assessments and implementing actions), rather than by providing detailed re-creations of aspects of the physical environment that are otherwise irrelevant to the decision problems confronting the participant (Omodei & Wearing, 1995).

3.6.3 *Simulation Fidelity Requirements*

The above discussion implies that: (a) only a moderate level of physical fidelity is required for re-creating safety-relevant scenarios, just sufficient to enable (b) the high level of psychological fidelity which is required. This emphasis on a high level of psychological fidelity is particularly important where a researcher's focus of interest is on those human (mental) factors underlying judgment and behaviour. Without an appropriate level of psychological fidelity researchers run the risk of investigating trivial and superficial aspects of the simulated task architecture, rather than the underlying structure of the real-world decision problems which the simulated task purports to represent.

We therefore add to the list of requirements already presented in this section the following two more general requirements.

U. The program-generated scenarios should possess a high level of psychological fidelity.

V. The program-generated scenarios should possess sufficient physical fidelity to enable the required high level of psychological fidelity.

4 Networked Fire Chief (Version 1.33)

In this section we introduce Networked Fire Chief (Omodei, Taranto, & Wearing, 2003) as meeting the identified requirements outlined above. Networked Fire Chief is a wildland fire fighting scenario generator specifically designed by for research into the psychological processes involved in decision making under conditions of complexity, time-constraint, risk, and uncertainty.

4.1 Program Description

Program Name
To avoid some potential confusion that might arise from the name Networked Fire Chief, it should be noted that Fire Chief was originally chosen (cf Omodei & Wearing, 1991) to convey an understanding of the key features of the program to members of the decision making research community in general, and military command and control researchers in particular. That is, the program was not initially developed with a view to its being used by experienced wildland firefighters (although subsequent program developments have, in fact, focused on the program's potential for such). It is appreciated the program name is, perhaps, more suited to a North American context. However, changing the name is likely to be confusing to those many researchers currently using it, or familiar with our research.

Fire Model
The default fire model is an empirical model which produces fire spread rates and fire shapes that have been reported by experienced wildland firefighters/instructors as being realistic. We draw attention to the fact that the aim of this model is to provide for psychological fidelity, rather than full physical fidelity, and as such we would not recommend this default fire model for use as an operational predictive tool or for training in finer points of fire behaviour. The default fire model is presented as Appendix B. There is the ability for program users to replace the program-default fire model with their own fire model (via the program's Fire Editor described immediately below).

Fire Editor
In anticipation of program users' requirements for a different fire model, Networked Fire Chief has been provided with a Fire Editor which allows the user to specify, as a dynamic linked library, a fire model of their choice. This does require some programming knowledge but is relatively straightforward to implement. The Fire Editor also allows the scenario developer to customise the appearance of fire icons according to various levels of fire intensity. A prototype *Spot Fire Editor* has been added as one of the Networked Fire Chief program enhancements that have been added for use in the Bushfire CRC.

Landscape Editor
Perhaps the greatest strength of the Networked Fire Chief simulation is its flexibility in enabling scenario *developers* to design a large number of diverse scenarios with relatively low time and cost overheads. For example, the Networked Fire Chief landscape editor allows a *developer* to define a large number of different landscape elements which can be as varied as grassland, pine forest, a rural/urban interface, and a variety of water resources. Landscape types are divided into three distinct categories; a consumable element which fires can burn (e.g. forest or residential house), a resource element which allows appliances to refill (e.g., rivers and dams), and a non-consumable element which cannot be affected by fire (e.g. major roads or rocky outcrops). The flammability characteristics of each consumable landscape type can be specified separately by the scenario *developer*.

Contour Editor
The user can draw onto the map lines to indicate landscape elements of equal elevation. The editor only allows the user to program legal contours (i.e., contour lines which do not cross). The elevation of all remaining landscape segments is estimated at run time. At present, the Networked Fire Chief program does not interface with Graphical Information Systems (GIS) data, however the creation of an interface to read this data would be a relatively straightforward programming task.

Appliance Editor
In Networked Fire Chief, the characteristics of fire fighting resources are also highly customisable (e.g. water capacity, appliance speed). Appliances can be set to be able to only extinguish low intensity fires, meaning that high intensity fires must be combated with control lines or aerial appliances. Appliances can also be vulnerable to being destroyed by fire, so that *participants* need to take care not to place these appliances in potential burnover situations. The program's pre-programmed (artificial intelligence) fire suppression strategies are also selected via the Appliance Editor.

Computer Network Station Editors
A number of separate editors are provided which allow each computer station in a Networked Fire Chief network to be separately configured. This allows quite complex incident management and communication structures to be implemented as required for a given research investigation.

Scrolling and Zooming Editor*:* The user can specify the simulation map scrolling and zooming permissions for each computer station. Each station may have as many zoom levels as required. For each zoom level the user is also able to define whether *icons* at that zoom level will be displayed in graphical or simplified form.

Zone Editor*:* The program user can divide the simulation map up into smaller subsections or any desired shape. Access to information and control of appliances in each zone can be specified separately for each computer station in the Networked Fire Chief network.

Information Display Editor: Timeliness and amount of information displayed at each computer station can also be separately specified. That is, the display of fires, appliance locations, fire warnings, resource availability, and wind conditions might be updated only infrequently on selected client stations. For example, an Incident Controller might have outdated information, while his/her subordinates, who are actually fighting the fires, can be continuously presented with up to date information. Quite complex information displays can be implemented. For example, one can restrict a participant's view of a fire incident depending upon the location of appliances such as tankers or forward observers, or upon the location of buildings such as residential homes or observation points. If no buildings or appliances are located in a particular area, then this area of the map can be made to appear greyed-out and the participant will be unaware of the development of a fire until an appliance enters that area and updates the information view. This feature is relevant given Australia's population dispersion where many areas of our country are largely uninhabited and fires can burn for hours before being reported.

Event Editor
An *Event Editor* allows for the precise specification of wind changes, fire initiation, and the provision of wind forecasts and fire warnings.

Program Output Files
Networked Fire Chief is capable of collating and automatically saving three distinct types of output file; a Statistics File, a History File, and a Replay File. These files allow *researchers* to examine in considerable detail the decision behaviour displayed by research *participants* together with the outcomes of their decisions.
The Statistics File includes summary information about amounts of different types of landscape burnt, how many commands *participants* gave to each firefighting appliances, how long each appliance spent being idle, refilling or fighting.
The History File includes a complete list, in chronological order, of all simulation events and all commands given by each networked *participant*.
The Replay File implements a complete on-screen replay of a scenario that a *participant* has previously played. A researcher would typically review a replay with a *participant* or *team of participants* in order to elicit further information on those human (psychological) factors that drove the decision-making processes operating during the trial.

4.2 Program Suitability for Investigating Unsafe Decision Making

Scenarios are easy and relatively quick to design, enabling a wide range of safety-relevant scenarios to be developed over a short period of time. The ease of editing all the aspects of the program described above without specialised programming expertise constitute an immense advantage of this program over potential alternative wildland firefighting simulation programs. The networking capabilities of Networked Fire Chief are as powerful as those of more sophisticated graphic-intensive programs. A high level of *participant* interactivity is provided, particularly with respect to information gathering and with respect to real time fire suppression activity. Extensive output data, together with the facility to replay scenarios for subsequent debriefing and analysis, enable the *developer* and *facilitators* to assess in fine detail *participant* performance. Despite not having three-dimensional graphics, the provision of detailed contour information, the ability to represent flame heights and water levels in dams, and a plausible fire spread model means that Networked Fire Chief has sufficient physical fidelity to support a high level of psychological fidelity with respect to: (a) the decision making processes involved in wildland fire fighting in general, and (b) the human factors which negatively impact on the quality of such decision making in particular.

An additional reason for selecting Networked Fire Chief for the present research is that the program is one which, for obvious reasons, we have had considerably more experience in using, than we have had with any alternative program (brief discussion is provided in the section immediately following). Furthermore, to the extent that further programming enhancements and refinements may be required, we can be reasonably confident that we have the skills to implement these.

4.3 Overview of Research Conducted with the Networked Fire Chief Program

Our research to date with the Networked Fire Chief program has mostly focussed on general psychological issues underlying command and control decision making from a military perspective (using university students as research participants). In these studies we have mostly investigated issues relating to command team structure (e.g., Clancy et al, 2003) and issues underlying systematic decision error (see Omodei, Wearing, & McLennan, 2000; 2002; Omodei, Wearing, McLennan, Elliott, & Clancy, in press).

Nevertheless, findings from our field research with the Melbourne Metropolitan Fire Brigade (see McLennan & Omodei, 1996; McLennan, Omodei, & Wearing, 2001a;

McLennan, Pavlou, Klein, 1999) suggest that many of the psychological issues relating to both command structure and systematic decision error (including those decision errors which compromise safety) are common to both military and emergency services response (see particularly McLennan, Omodei, & Wearing, 2001a).

5 A Review of Potentially Relevant Computer-Based Wildland Firefighting Simulations

In order to determine the availability of other wildland firefighting simulators potentially suitable for the targeted investigation of unsafe decision making in wildland firefighting contexts, we conducted a review of those wildland firefighting programs we were able to locate, according to the simulation requirements we described in Section 3 (commencing on page 8) above.

First, we enquired about which wildfire simulators local fire agencies had used or considered using. Secondly, we conducted an extensive internet search (using the Google™ search engine) for any wildland firefighting simulation program that had the potential to meet the requirements listed in Section 3. As simulations were located, we acquired and tested those which were made available to us.

In this report we provide descriptions of those simulations that appear to meet at least some of these simulation requirements for the systematic investigation of the human (psychological) factors underlying safety-compromising decisions. In selecting simulations for consideration in this report, we restricted ourselves to those simulations which afforded opportunities for *participants* to alter the spread of the simulated fires by engaging in fire suppression activities. Given the present project's research focus on the behaviour of firefighters, rather than on the behaviour of wildfires, a minimum requirement for investigating firefighter decision making are experimental scenarios which provide realistic opportunities of such decision making with respect to fire suppression. As a result we have not included programs such as SiroFire (CSIRO Forestry and Forest Products, 1998) in this review. We acknowledge that although the fire behaviour modelling implemented in programs such as SiroFire may be sufficiently accurate for use as operational decision-support tools and/or as training demonstrations of fire behaviour, they are nevertheless unsuitable for our present research purposes in so far as they provide no opportunities for decision making and actions relating to fire suppression. That is they do not meet Category 3 requirements, namely "Affords opportunities for a full range of fire suppression activities and command, communication, and control structures".

We located the following seven computer-based wildfire simulations (inclusive of Networked Fire Chief) that we regarded as being potentially suitable (*should the reader know of any other potentially suitable wildland firefighting simulators that we might have overlooked, we would be most grateful for this information -- contact details are provided at the end of this report*). We present and discuss each simulation in the order in which we believe the programs to have been developed, commencing with the earliest such program.

1) Farsite
2) Networked Fire Chief
3) FireStorm Pro
4) Collaborative Forest Fire Fighting Simulation Tool
5) SimViz/3500ICS
6) 3-D Fire Sims
7) VectorCommand Wildfire (IMT)

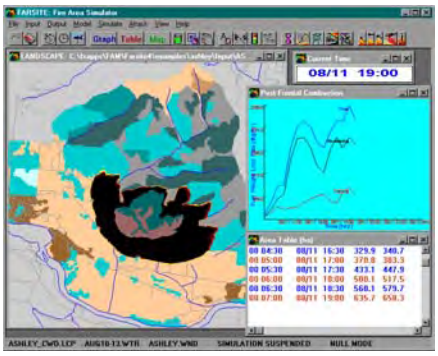
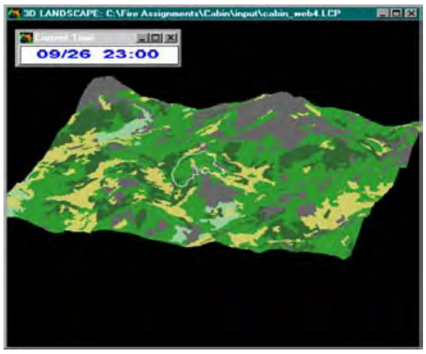
We were able to obtain full copies of three of these programs; namely Farsite, FireStorm Pro, and Networked Fire Chief. For the remaining four programs we obtained programming documentation of varying levels of detail.

As our research interest is less concerned with predicting fire behaviour and more concerned with understanding and predicting human decision making behaviour, the programs we have selected may not implement fire models of sufficient accuracy to serve as operational decision support tools. However, for human factors research purposes, the lesser sophistication in the modelling of fire behaviour in the selected programs is more than compensated for by the provision of realistic fire suppression capabilities.

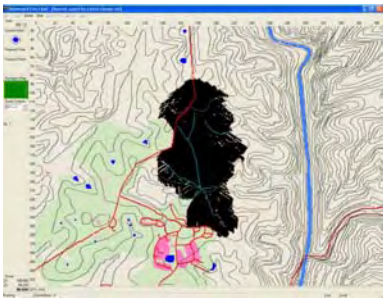
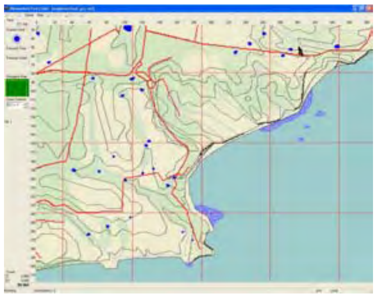
In the section immediately following we present a systematic description and review of the seven selected programs. As part of this review we examined each program against the 22 (A - V) simulation requirements presented in Section 3 above. After presenting our review of each of the selected programs, we provide a comparative review of the programs with respect to their suitability for investigating human factors issues involved in safety-compromising decision making.

Although the focus of our review was on those characteristics which determined a program's suitability for the psychological investigation of firefighter decision making, we suggest that any (or all) of the seven wildfire simulation programs reviewed in this report could be examined by End User Fire Agencies as a potential source of training simulations. We have tried to present sufficient information on each of the programs reviewed to allow personnel involved in designing or running training courses to begin to assess suitability for their own purposes. Of particular note is the potential that several of the reviewed simulation programs offer for immersive Scenario Oriented Fire Training (SOFT). Note that this latter approach to training is an application to fire training of the LOFT (Line Oriented Flight Training) procedures developed by NASA for aviation training. The SOFT approach, which is being progressively adopted for wildland firefighter training by North American agencies incorporates key aspects of (a) Klein's (1996) Recognition Primed Decision (RPD) Making model and (b) Crew Resource Management (CRM) principles (cf Okray & Lubnau, 2004). Further information on this training approach as applied to firefighting can be found in the NSW RFS training publication AF/1 – (2003) Firefighter Safety – The Human Factors, and in Okray and Lubnau (2004).

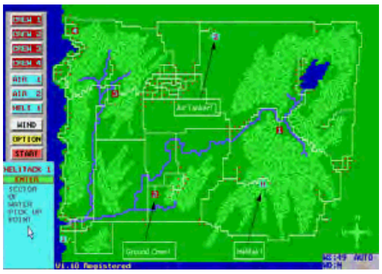
5.1 Summary Description of Wildland Firefighting Simulators Potentially Suitable for Investigating Unsafe Decision Making

1)	***FarSite (version 4.04)***	
Screenshots	 	
Display	Top-down, 2-D display, optional isometric 3-D display	
Networked	No	
Scenario Design Flexibility	Medium	
Description	Farsite was developed by Mark Finney and Rob Seli, primarily for the United States Department of Agriculture (USDA) Forest Service. It is currently used by a number of United States fire agencies, including the US Department of the Interior (USDI) National Park Service, and USDA Forest Service. In addition to simulating fire spread, Farsite also simulates direct and indirect ground attacks and air attacks. Farsite is capable of simulating a number of fire types such as crown fires, surface fires, and spotting. In order to represent real world terrain, the program also uses spatial landscape information derived from Geographic Information Systems (GIS).	
Strengths	Advanced fire spread modelling incorporating an extensive array of variables that are likely to affect fire spread activity.	
Weaknesses	Farsite's biggest drawback is that scenario development is extremely time consuming and difficult. While Farsite is an excellent tool for predicting wildfire spread, the range of potentially useful scenarios for examining safety-relevant decision making is limited. In particular the program is not able to be networked across a number of computers, making it difficult to investigate decision making beyond the crew-leader level.	
Requirements Met	9	C, E, H, J, L, O, T, S, V
Requirements Failed	13	A, B, D, F, G, I, K, M, N, P, Q, R, U
Availability	Available.	
Cost	Free	
Source	http://www.farsite.org/	
Summary	For the purposes of predicting and teaching fire spread behaviour, Farsite is an excellent simulation. Notwithstanding, there are a number of reasons why Farsite is unsuitable as a simulator for examining safety compromising decision making. Firstly, even though it does allow *participants* to control and instruct ground and air crews in suppressing outbreaks, the	

	controls are non-intuitive and awkward. Farsite also fails with respect to other requirements identified in this report. Farsite is not networkable and thus is largely unsuitable for investigating decision making in teams (from strike teams to incident management teams). Scenario development is time consuming as a large number of variables that potentially effect fire spread need to be considered.

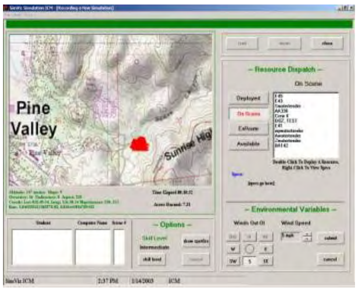
2)	***Networked Fire Chief (version 1.33)***
Screenshots	 
Display	Top-down, 2-D display
Networked	Yes. Networked Fire Chief can be networked over any number of computers, allowing for simulations to be run real time over both a Local Area Network (LAN) or a Wide Area Network (WAN), including via standard modem connection to the internet.
Scenario Design Flexibility	Very High
Description	**Note 1**. *Networked Fire Chief was originally developed under funding support from the Defence Force and the Australian Research Council to study decision making in distributed teams in general - such as military command and control – (Omodei et al., 2001). Nevertheless developments in the program over the last decade have been made with a view to using experienced wildland firefighters as research participants.* **Note 2.** *Several programming enhancements have been made to the Networked Fire Chief program as part of the approved work for Phase 1 of the Bushfire CRC "Enhancing Safety" project. For purposes of comparison with other wildfire simulation programs, in this section we review the version of Networked Fire Chief that existed prior to commencement of the Bushfire (Networked Fire Chief, Version 1.33, Omodei, Taranto, Wearing, 2003). We note here that these programming enhancements (summarised in a later section of this report) are relatively minor in comparison with the extensive features which existed in the pre-existing version (Version of 1.33) of the program.* Networked Fire Chief's fire behaviour model is relatively unsophisticated but does take into account variables such as wind strength, wind direction, temperature, relative humidity, terrain slope, fuel density, moisture content, and flammability characteristics. An efficient icon editor allows for the presentation of much 3-D information in a 2-D screen format (such as flame heights and water levels in dams). The simulator also allows for full *developer* flexibility in the specification of landscape characteristics and elevation, and over types of ground-attack and aerial-attack units, enabling a wide range of fire suppression activities to be implemented. The program comes with several pre-programmed (artificial intelligence) fire suppression strategies that the *developer* can select if the intention is to study decision making at strike team leader level or above. The program can also be interfaced with other hardware, such as eyetracking and physiological monitoring equipment,
Strengths	Networked Fire Chief is highly customisable allowing the *developer* (a) great flexibility in appearance and functional behaviour, (b) comprehensive data logging, (c) a real-time replay facility, (d) the facility to interface with other hardware, and (e) the ability to run its scenarios over the internet. With minimal training, novice developers can input large areas of complex topography relatively quickly.

Weaknesses	Displays are topographical in two-dimensions only. This makes it difficult to communicate some potentially relevant fire information such as bark characteristics and smoke haze. Opportunities to alter fire initiation and appliance behaviour at run time are minimal.	
Requirements Met	21	A, B, C, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V
Requirements Failed	1	D (partly failed)
Availability	Available.	
Cost	None	
Source	http://www.latrobe.edu.au/psy/research/cdrg/nfc.html	
Summary	Despite the lack of rendered three-dimensional graphics that are included in other wildfire simulators, Networked Fire Chief represents a cost-free, highly flexible tool that has been specifically designed for research into decision making in teams..	

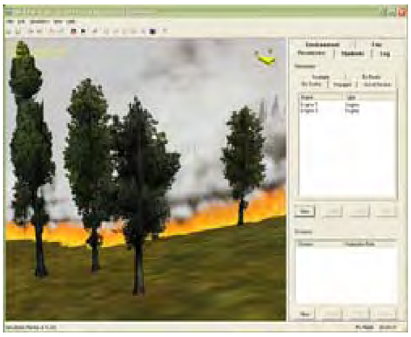
3)	***FireStorm Pro***	
Screenshots	 	
Display	Top-down, 2-D display	
Networked	No	
Scenario Design Flexibility	Medium	
Description	FireStorm Pro was developed by a private software company called Cricket Software, and is currently in use by the U.S. Forest Service, the U.S. National Park Service, and the U.S. Bureau of Land Management. FireStorm Pro allows the operator to use four ground crews and two air tankers to battle blazes on a map of 180,000 acres. Fire is affected by wind conditions and terrain. The operator can create control lines and drop retardant to contain the fire. The simulated map contains various terrains, roads, structures, lakes, & rivers. A status bar keeps track of acres on fire, acres burned, structures lost and simulation time. Wind changes can occur randomly or be specified by the *developer*. FireStorm Pro is available with a map editor so that the developer can create their own scenarios.	
Strengths	Advanced Fire suppression options including helitak and use of fire-retardant	
Weaknesses	Despite the landscape design editor being more advanced than some other programs reviewed (e.g. Farsite) it still falls short of some other simulators (e.g. Networked Fire Chief) with respect to flexibility of scenario design. Furthermore, FireStorm Pro does not include networking capabilities.	
Requirements Met	11	C, D, E, F, H, I, J, L, M, O, T
Requirements Failed	11	A, B, G, K, N, P, Q, R, S, U, V
Availability	Available.	
Cost	Approximately $60 US	
Source	http://www.firesims.com/main.htm	
Summary	FireStorm Pro, although having a reasonable level of both physical and psychological fidelity, falls short in a number of key requirements. The range of incidents that can be simulated is somewhat limited. Most importantly, the simulation lacks networking features.	

4)	***Collaborative Forest Fire Fighting Simulation Tool***	
Screenshots	 	
Display	All displays are directly set in 3D rendered graphics	
Networked	Yes. The program is fully networked and the information presented to stations can be fully customised depending upon the rank or role of the participant.	
Scenario Design Flexibility	Very High	
Description	This software tool was developed for the Civil Safety and Defense Department of the French Ministry of Internal Affairs. The simulation appears very similar to SimViz/3500ICS (described below) in look and feel. The landscape is rendered using three-dimensional graphics, and covers an area of several thousand sq kms in the South of France. Participants are able to control a number of ground and aerial vehicles in order to suppress the simulated fires. Networking capabilities means that a number of *participants* can control the simulation at any one time and can be physically co-located or geographically separated. The system also includes a 'god mode' screen, typically displaying a two-dimensional map of the landscape and fire situation. This enables a *facilitator* to dynamically alter the course of the simulation by adding new fires, etc.	
Strengths	Perhaps the strongest feature of the program is the ability to allow the facilitator to dynamically introduce new events as varied as spot fires and traffic incidents, via a simple 'drag and drop' function. The program is fully networked with the facility to customise the information presented to stations. A wide range of appliance types are included, and appliance numbers are essentially unlimited.	
Weaknesses	The scenario terrain has been developed as a one-off venture, and represents the South of France so the program is unlikely to be suitable for generating scenarios for Australian landscape. The cost involved in developing an area of Australian landscape would be very high, and Australian Fire Agencies have already made a commitment to acquire a somewhat similar project in VectorCommand Wildfire (IMT), described below.	
Requirements Met	**Note**. *The following assessments are provisional until more information can be obtained*	
	14	A, B, D, I, J, K, L, M, O, P, Q, T, U, V
Requirements Failed	8	R, S, C, E, F, G, N, H
Availability	Theoretically the program could be purchased, but requires a physical installation as well as software.	
Cost	$1.5 Million (approximately)	
Source	http://geovrml.com/eng/CIFSC/index.html	

Summary	Upon initial inspection the program appears to be very promising, meeting a number of key requirements such as networking features, the ability to dynamically alter the course of events, and the ability to create a range of safety-relevant scenarios. Further information about the software, such as availability for purchase and cost is being sought. As with VectorCommand Wildfire (IMT) and SimViz/3500ICS, more information needs to be collected on the simulation before its suitability for the proposed research can be fully assessed. We are in the process of obtaining this information.

5)	***SimViz3500/ICS***
Screenshots	 
Display	The facilitator console is a graphical user interface (GUI) that controls the simulator. The student consoles are a combination of a GUI and a 2D image created from a rendered 3D graphic model
Networked	Yes. Up to two instructor stations and six participant stations can be linked via either a Local Area Network (LAN) or a Wide Area Network (WAN)
Scenario Design Flexibility	High
Description	SimViz 3500ICS was developed by the STAR Technology Corporation, who have among their recent clients, the National Fire Academy and the USDA Forest Service. SimViz 3500ICS is a fully integrated wildland firefighting simulator that encompasses both software and custom-ordered PC-based hardware. However, the program can also be run on standard PC platforms and uses a combination of two-dimensional and three-dimensional graphics. The simulation has the ability to network up to two *facilitator* stations and up to six *participant* stations. *Facilitator* stations can be at the level of incident management team or strike team leader, depending on the simulation set-up. The simulator is fully interactive and incorporates advanced fire suppression activities, including lines that are created by dozers, tankers or hand crews.
Strengths	An incident management "interface" allows the *developer* to either exercise control over the events that are displayed to the *participants* or to have the events unfold automatically according to a predefined event list.
Weaknesses	The program is expensive to acquire. Due to the 3-D rendered graphics, scenario design has to occur at the programming level rather than at the level of the local developer. In other words, the simulation only comes with one simulated, pre-defined landscape area.
Requirements Met	**Note**. *The following assessments are provisional until more information can be obtained* 15 — A, B, D, I, J, K, L, M, O, Q, R, S, T, U, V
Requirements Failed	7 — C, E, F, G, H, N, P
Availability	Available.
Cost	Approximately $37,500 US comprising one fully customized scenario.
Source	http://www.startechcorp.com/index.htm
Summary	Upon first inspection SimViz3500ICS meets a number of key requirements including, networking capabilities, the ability for the *developer* to alter the course of events dynamically, and the ability to engage in advanced fire suppression activities. We are endeavouring to gather more information about the program, and with this added information we will be in a stronger position to comment about its suitability for

	investigating the human factors underlying safety compromising decision making. We are in the process of obtaining this information.

6)	***3D Fire Sims***
Screenshots	 
Display	3D rendered graphics
Networked	Yes. Two or more computers can be linked, including at least one facilitator computer
Scenario Design Flexibility	High
Description	3D Fire Sims was developed through a partnership between the US National Fire Academy, the USDA Forest Service and a private software company (Dynamic Animation Systems). The software operates on a windows-based PC platform and simulates a physically realistic fire propagation model that takes into account fuel types, weather conditions and topography. Participants have the ability to request resources and to construct fire lines to hinder the propagation of fires. *Facilitators* also have the ability to dynamically alter environmental conditions (such as wind direction and strength). *Participants* have minimal interaction with the interface and issue commands via a *facilitator*, who manages the fire appliances on their behalf. The program provides *participants* with direct visual feedback about the results of their suppression activities. The simulation can also be recorded for replay and debrief after each session. The program provides a scenario editor which has the ability to define environmental conditions, the resources available to the participant, and the role that each networked computer will play in the scenario.
Strengths	Lack of information makes it somewhat difficult to determine the strengths and weaknesses of this program. Nevertheless, obvious strengths are the programs networkability and flexibility in allocating different roles to each networked computer. The addition of a scenario editor and the ability for the facilitator to dynamically alter the course of events shows promise for the program's ability to quickly design a range of safety-relevant decision scenarios.
Weaknesses	While the addition of a scenario editor is a plus, the process by which landscape is added to the scenario sounds laborious and time consuming. Little information is also available about the implementation of fire suppression activities and upon first inspection, it appears that the only appliance types that the program can simulate are tankers and dozers.
Requirements Met	**Note**. *The following assessments are provisional until more information can be obtained* 19 | A, B, C, D, E, F, G, H, I, J, K, L, M, O, Q, S, T, U, V
Requirements Failed	3 | N, P, R
Availability	Unknown.
Cost	Unknown.
Source	http://www.d-a-s.com/USFS.html

Summary	Upon initial inspection, 3D Fire Sims looks promising mainly due to its networkability and flexibility in scenario implementation. However further information will need to be collected in order to evaluate its suitability for easily and quickly developing a range of safety-relevant scenarios. The programs availability to the Bushfire CRC and the program cost are also unknown at the time of preparing this report. As this program is still under development, we will need to wait for information and a demonstration of the working program would be needed in order to make a fully informed decision as to its suitability for the proposed research.

7)	*VectorCommand Wildfire (IMT)*	
Screenshots	Images not available	
Display	From information in the IMT (Wildfire) PROJECT PLAN, 11 May 2004 (supplied to us by Sandra Lunardi, project officer, AFAC), and personal communication from Mike Griffin (VectorCommand, July 27, 2004), VectorCommand Wildfire (IMT) will use 2D graphical representations. The usual VectorCommand 3D graphical visual representations are considered unimportant as Incident Management Teams (IMT's) are located at a significant distance from the fire incident itself.	
Networked	Yes. Details unavailable	
Scenario Design Flexibility	High	
Description	Drawing on information provided in the IMT (Wildfire) PROJECT PLAN, together with the information communicated by Mike Griffin, VectorCommand Wildfire(IMT) is an instantiation of VectorCommand which has been specifically developed for training Australian wildfire Incident Management Teams (IMTs). Other VectorCommand scenarios are already in use in many countries (including the United Kingdom, North America, and Australia) simulating a range of urban incidents (such as, industrial fires, aviation accidents, and transport accidents). Wildfire IMT will use one base wildfire scenario in order to simulate three general phases of wildfire fighting requiring the involvement of an Incident Management Team, namely, (i) mobilisation, (ii) suppression/maintenance and (iii) demobilisation. The Wildfire IMT engine will allow *facilitators* to provide 'injects' into the simulation at appropriate times, and information will be filtered through to the IMT as it would be in a real incident. To this end, Wildfire IMT requires a degree of 'role-playing' by *facilitators.* The program also simulates various physical communication artefacts through which information is typically filtered, such as facsimile, e-mail, mobile phone text messaging and hand-held portable radio interfaces. The scenario will provide enough flexibility to be used by a range of emergency response services.	
Strengths	Wildfire IMT has the ability to simulate the physical and psychological conditions under which Incident Management Teams operate in real-world wildland fire fighting. It therefore has large potential as a tool for investigating the decision making processes involved in large-scale incident management, including the operation of safety-relevant human factors at the level of the IMT	
Weaknesses	It is unclear the extent to which these advantages of Wildfire (IMT) will apply to the investigation of safety-relevant decision making on the fireground (i.e., decision making by crews and strike teams). It is also unclear what level of flexibility in scenario development Wildfire (IMT) will afford. The time and associated cost of developing a range of varied safety-relevant fireground scenarios may limit its use for the current project	
Requirements Met	**Note**. *The following assessments are provisional until more information can be obtained*	
	17	A, B, C, D, I, J, K, L, M, N, O, P, Q, S, T, U, V
Requirements Failed	5	G, H, E, F, R

Availability	To be ready for use mid 2005.
Cost	To be advised
Source	http://www.vectorcommand.com/
Summary	VectorCommand Wildfire (IMT) promises a sophisticated training tool of high psychological fidelity which may prove suitable for systematic research into safety compromising decision making. The high level of fidelity of the base scenario with respect to Incident Management Team decision making may possibly be achieved at the expense of flexibility to modify this base scenario to investigate specific safety issues at lower ranks on the actual fireground. However, where such modifications can be achieved, the program may well prove to be suitable for at least some of our research purposes. As this program is still under development, we will need to wait for information and a demonstration of the working program would be needed in order to make a fully informed decision about its suitability for the purposes of the D2.3 research project.

5.2 Comparative Evaluation of Computer-Based Wildfire Simulations

We conclude that of these seven programs Networked Fire Chief is the best, and most cost-effective, tool currently available to enable the proposed research to be undertaken in the time frame required. The ease of editing all the aspects of program behaviour by way of the in-built scenario editors without specialised programming expertise constitutes an immense advantage of this program over the potential alternative wildland firefighting simulation programs. Furthermore, in addition to meeting almost all of the simulation requirements we identified, many of the Bushfire CRC staff already working on the "Enhancing Safety" project have considerable familiarity with the program and experience in using it as a psychological research tool.

A number of the remaining computer-based wildfire simulators reviewed above show promise for investigating human factors issues involved in safety-compromising decision making. It is apparent that some highly sophisticated simulations are being developed such as SimViz/3500ICS and the Collaborative Forest Fire Fighting Simulation Tool. Such wildfire simulations are likely to place research *participants* in highly immersive environments but the potential cost of these programs is likely to prohibit their use in the current project. However, 3D Fire Sims and VectorCommand Wildfire (IMT), the two simulators that are currently under development, might well prove to be cost effective alternatives or complements to Networked Fire Chief for the research into unsafe decision making. As these programs become available we will examine them for their suitability for use in the present project. As VectorCommand Wildfire (IMT) is being taken up locally, we are particularly interested in examining this simulator because of the added advantages of local fire agency personnel developing familiarity and expertise in its use.

6 An Overall Strategy for Developing Networked Fire Chief Safety Scenarios

In this section we briefly outline an overall research strategy for using Networked Fire Chief to generate test scenarios of the maximum level of sensitivity (i.e, sensitivity for revealing important human factors underlying unsafe decisions).

First and foremost, careful attention will need to be given to developing scenarios of the required level of psychological fidelity (see Section 3.6, pp 10-11, for an expanded discussion of the distinction between physical and psychological fidelity). The development of suitable scenarios will require close collaboration among (a) fire agency personnel who have expertise in fire behaviour and fire suppression strategies, (b) fire agency personnel who have experience in the use of training simulations, and (c) project staff who have experience in using and adapting simulators for controlled, systematic research.

Furthermore, advances in the understanding of fire behaviour and/or advances in fire suppression strategies and technologies (both within, and external to, the Bushfire CRC) will be considered for possible programming extensions to Networked Fire Chief. Note that one of the several advantages of using Networked Fire Chief over alternative simulation programs is that it will be a straightforward matter to undertake the minor programming tasks likely to be involved in modifying the underlying fire spread model and appliance capabilities. Of particular interest is the proposed work under the leadership of George Milne in project A5 (Bushfire Spread Simulation and Modelling). Although it seems unlikely that work on the A5 project will be completed in time for the work proposed in the current D2.3 (Enhancing Safety) project, we will take particular note of developments in this (A5) project, not only for any implications for Networked Fire Chief, but also as a complementary source of experimental scenarios.

7 Programming Enhancements to Networked Fire Chief

In this section we document several programming extensions we have made to Networked Fire Chief Version 1.33 to increase the program's suitability for research involving firefighters familiar with wildland fire behaviour and fire suppression strategies. Some, but not all, of the base landscape scenarios presented in the following section take advantage of these programming enhancements.

1. *Developers* can now specify separately for each networked computer station which appliance types are visible to that station, and of these appliance types, which can be controlled from that station (i.e., deployed for firefighting).
2. A *prototypical* spot fire feature has been implemented. Different landscape types can be allocated probabilities that a fire currently burning on that piece of landscape will ignite a spot fire downwind. The distance at which the spot fire is likely to occur can also be programmed into Networked Fire Chief.

All other features implemented in the base landscape scenarios presented in the following section were achieved using the pre-existing Networked Fire Chief Version 1.33 editors.

Note.
The latest version of Networked Fire Chief, together with the base scenarios described in this report, are available from Matt Walshe, Complex Decision Research Group, La Trobe University: m.walshe@latrobe.edu.au.

8 Networked Fire Chief Base Landscape Scenarios

In this section we present a suite of base landscape scenarios that were created using Networked Fire Chief to be evaluated for suitability for presentation of safety threats. In selecting landscape areas for these base scenarios we drew upon four complementary sources: (a) actual areas in which safety-compromising incidents had been reported; (b) actual areas currently in use as field simulation training and assessment exercises, (c) areas specially created for use in wildland firefighter training programs, and (d) areas specially created by us for the targeted investigation of proposed decision making errors. These scenarios range from the recreation of the area involved in the Linton/Midlands fire of December 1998, to a completely fictitious scenario designed to experimentally investigate a potential safety-compromising decision bias, namely the tendency to attempt to use more resources than one can manage. All the scenarios described below can be run on a single computer station or networked over as many computers as desired.

These scenarios, together with the Networked Fire Chief program that is required to run them, are available for use/inspection by all persons/agencies involved in the Bushfire CRC (contact details are provided at the end of this report). A background in computer programming is not required to create or edit Networked Fire Chief scenarios and we are available to assist anyone who wishes to create their own scenarios or to edit those we have already developed as part of the "Enhancing Safety" project.

Linton

This scenario is a re-creation in Networked Fire Chief of an actual area in which a safety-compromising incident took place (the Linton/Midlands December, 1998 fires). We have chosen to simulate this particular area for two reasons: (a) We are ourselves familiar with the area, and the events involved in the various stages of this fire, having been contracted to prepare a Human Factors report on the incident for the Coronial Inquiry (McLennan, Omodei, Wearing, 2001b); and (b) many readers of this present report are also likely to be similarly familiar with the fire and associated events, and therefore able to recognize their implementation as a Networked Fire Chief scenario. Out of respect for those persons who were involved in any way with the actual fire and associated events (particularly the loss of lives), we have chosen to limit our focus to the first attack phase of this fire. We have demonstrated this re-creation to several senior CFA wildfire instructors, who have assured us that the simulated fires do, in fact, behave as the actual fires being simulated were reported to have behaved.

Figure 1 shows a map of the area involved in the Linton fire with computer-simulated spread of the early phase of the fire (when it crossed Snake Valley Road). To portray the area with the greatest level of detail, for this map North is to the left side of the screen (in all subsequent scenarios convention is followed in having North to the top of the screen). To illustrate several of the features of Networked Fire Chief, Figure 2 portrays a zoomed-in image of part of the fire front using icons to indicate relative fire intensities. The Networked Fire Chief re-creation of the incident is presented in detail in Appendix C.

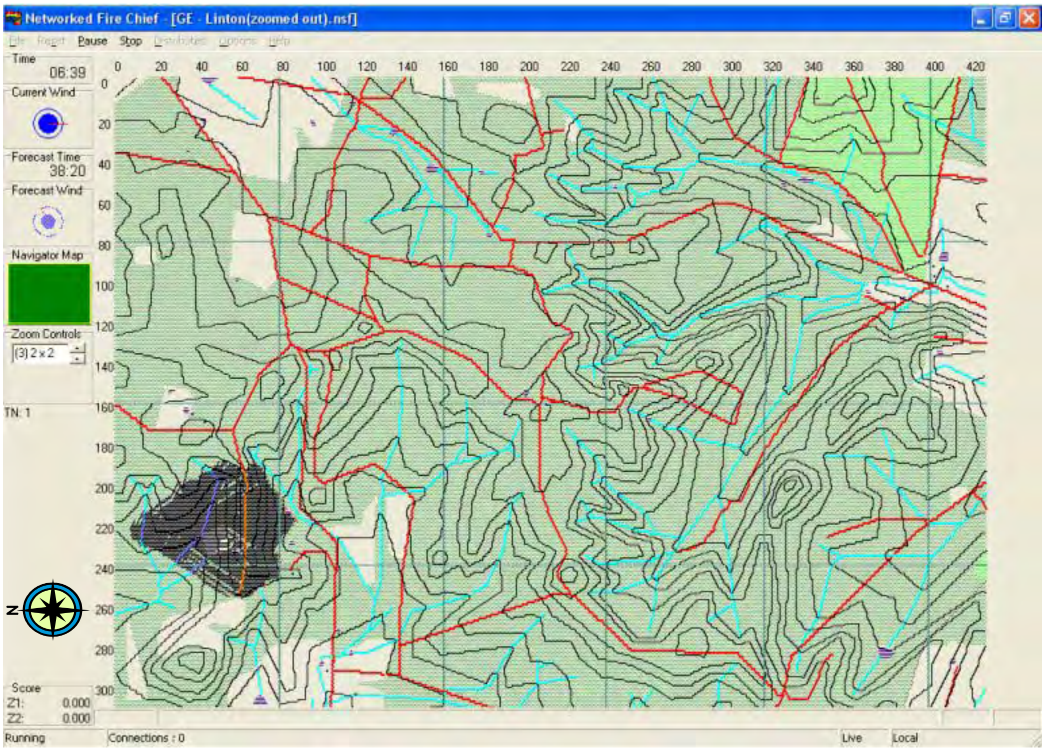


Figure 1: Networked Fire Chief scenario showing re-creation of the attack phase of the Linton fire (point of fire origin on far left of screen)

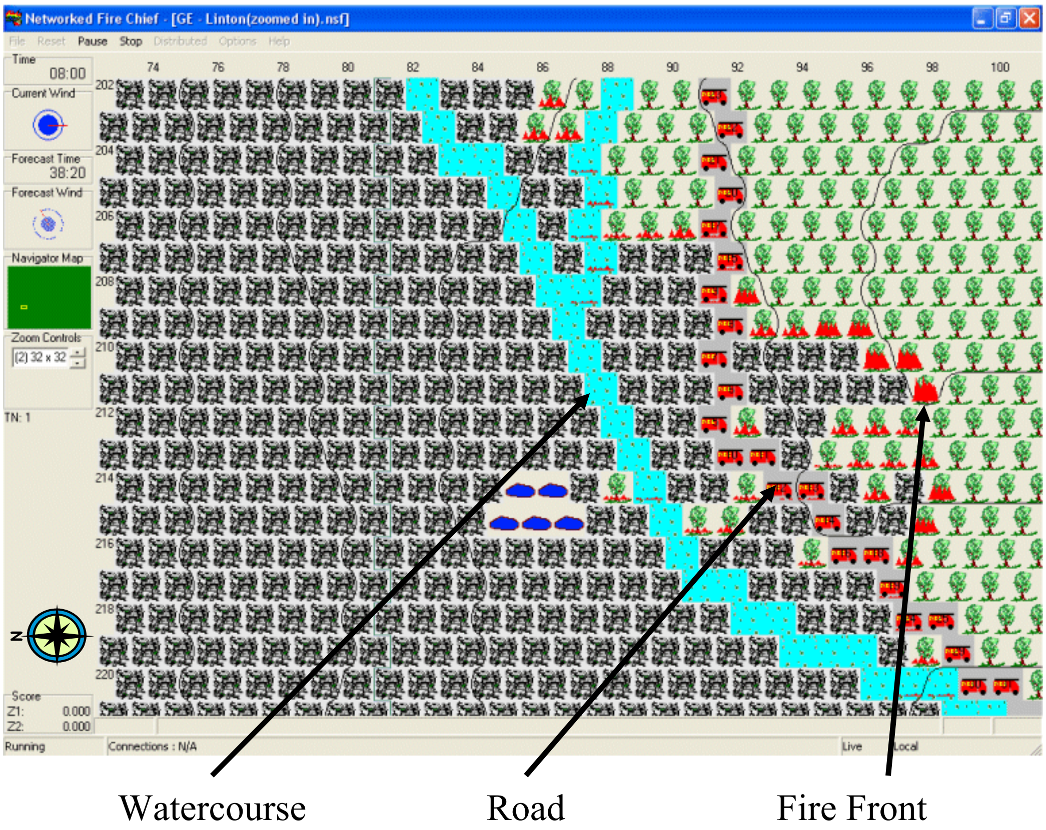


Figure 2: Linton fire moving South from a watercourse to cross Snake Valley Road (note fire intensities increase as the fire crosses the road on the uphill slope)

Anglesea

Wildfire field simulation training and assessment exercises which have been progressively refined over the years by various rural fire services constitute another source of potentially useful safety-relevant scenarios. We have selected several such exercises currently used by the Victorian Country Fire Authority, obtaining the relevant landscape details from the VicMap 1:25,000 topographic series. This information has been supplemented with information obtained from discussions with senior wildfire instructors in the respective regions. Such information has included landscape flammability characteristics and various unmapped features of potential relevance to firefighting.

In addition to providing a set of base landscape scenarios for our own use in the Bushfire CRC "Enhancing Safety" research project, such scenarios might also make a contribution to training. Each region invests a lot of creative effort and local knowledge in developing field exercises to train and assess staff. Such effort and knowledge could be shared across regions, with the field simulation exercises in one region being used as dynamic table-top exercises in other regions. This could be readily implemented by creating Networked Fire Chief simulations of these field exercises and sharing/swapping such simulations across regions.

Figure 3 portrays one such area currently in use for field simulation training. The area represented in this Networked Fire Chief landscape scenario includes the popular summer tourist area surrounding Bells Beach on the Victorian Surf Coast.

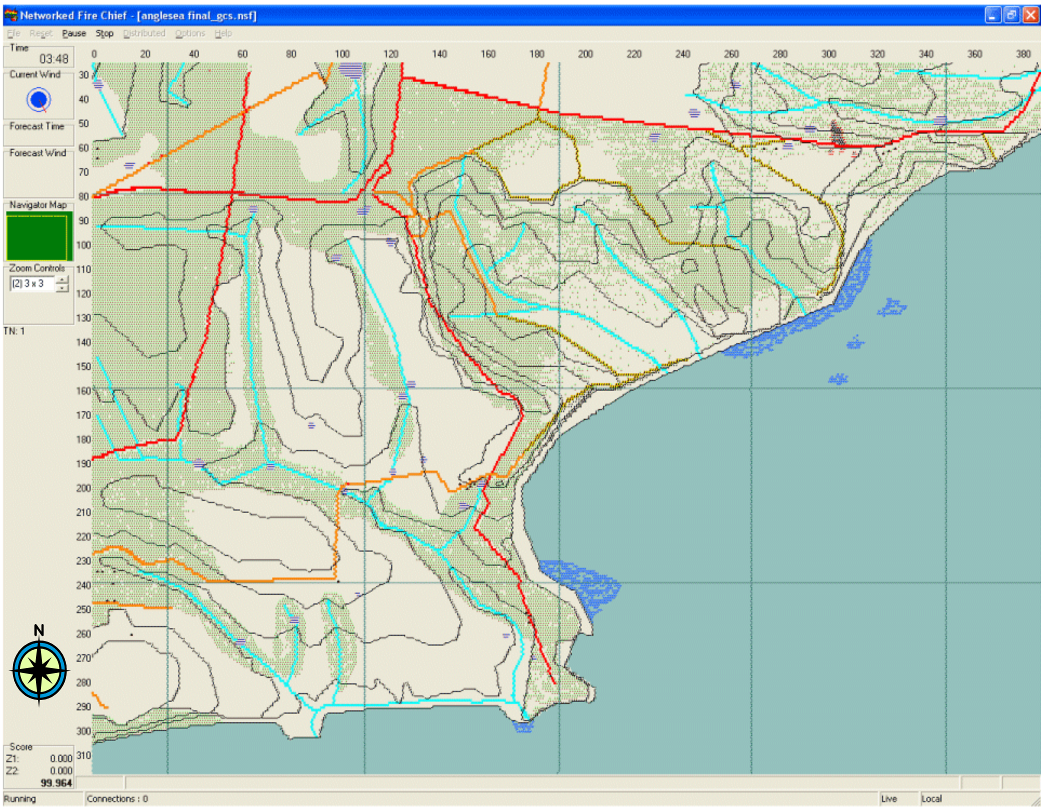


Figure 3: Networked Fire Chief scenario with a small simulated fire spreading South East towards Bells Beach on the Victorian Surf Coast

Rawson

Figure 4 portrays another area currently in use for field simulation training. The area represented in this Networked Fire Chief landscape scenario includes the township of Rawson to the east of the Thompson River. Potentially safety-relevant incidents which could be added to this landscape include the effect on fire spread of the steep slopes either side of the river.

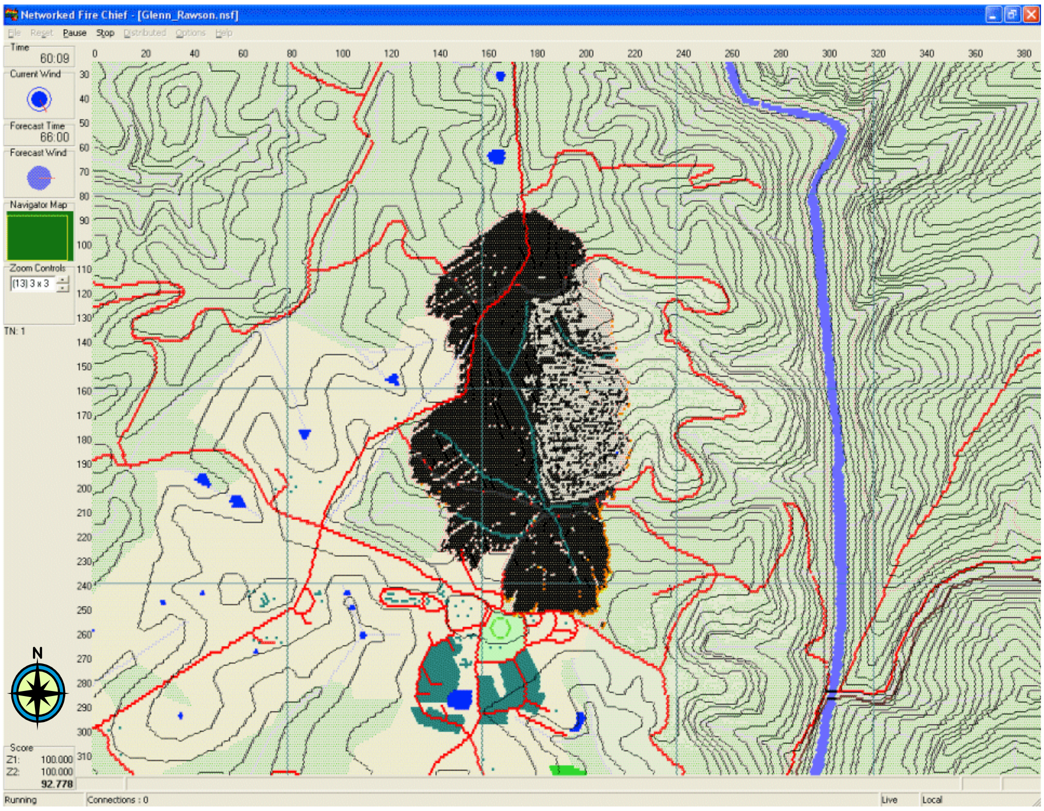


Figure 4: Networked Fire Chief scenario with simulated fire spreading South East towards the township of Rawson (Gippsland)

Lakes Entrance

Figure 5 portrays yet another area currently in use for field simulation training. The area represented in this Networked Fire Chief landscape scenario comprises forested area to the North of Lakes Entrance in East Gippsland.

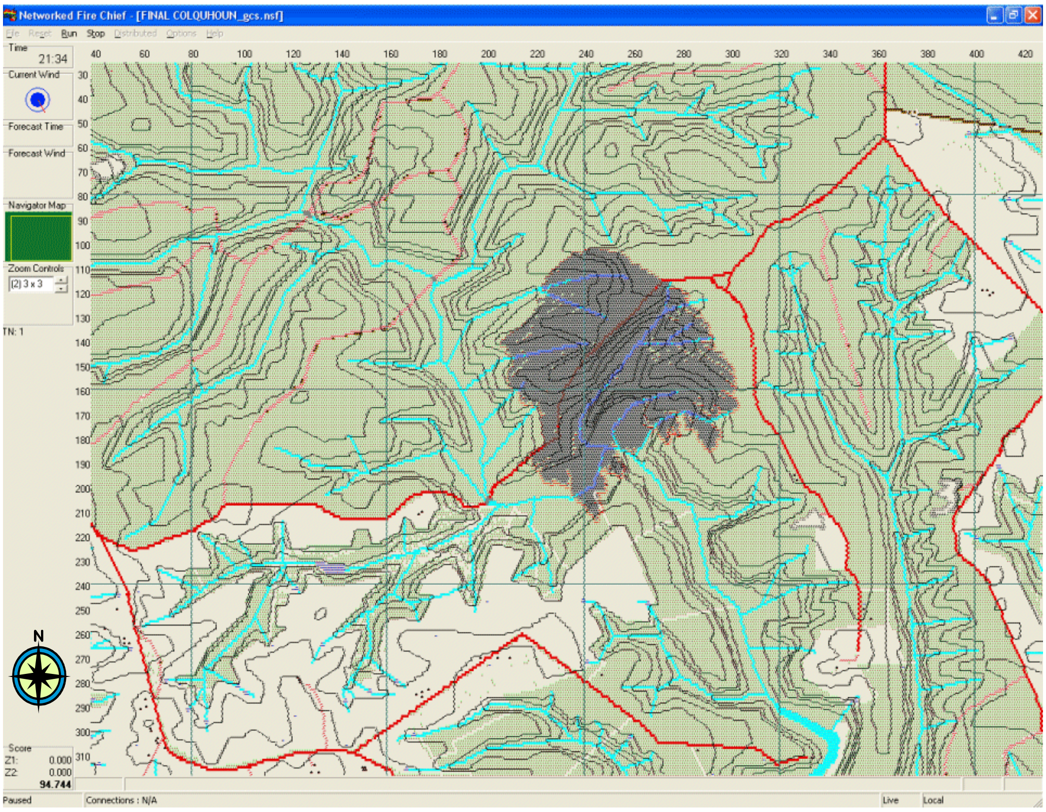


Figure 5: Networked Fire Chief scenario with a small simulated fire spreading South East towards Lakes Entrance (East Gippsland)

Downhill Fireline Construction Exercise

Another source of safety-relevant decision scenarios are tactical decision games (TDGs, alternatively called table top exercises) whether these be of actual fires that have occurred, interesting landscape areas, or completely fictitious areas. The selected scenario depicted in Figures 6 & 7 was sourced from a safety refresher training manual published by the US Bureau of Land Management Office of Fire and Aviation. Details on this scenario are provided in Appendix D. This scenario illustrates the potential to implement in Networked Fire Chief best-practice table-top exercises sourced from any fire service/any country. In this particular exercise, the participant is asked to complete a fireline construction between points A and B on the map. They have to keep in mind safety concerns and ways of mitigating such concerns, particularly the entrapment risk to the dozers.

Advantages of implementing such tactical decision game type exercises as computer simulated scenarios include the ability to allow participants to interact in a dynamic manner with the initially presented scenario, and to observe in real time the likely outcome of their ongoing decisions.

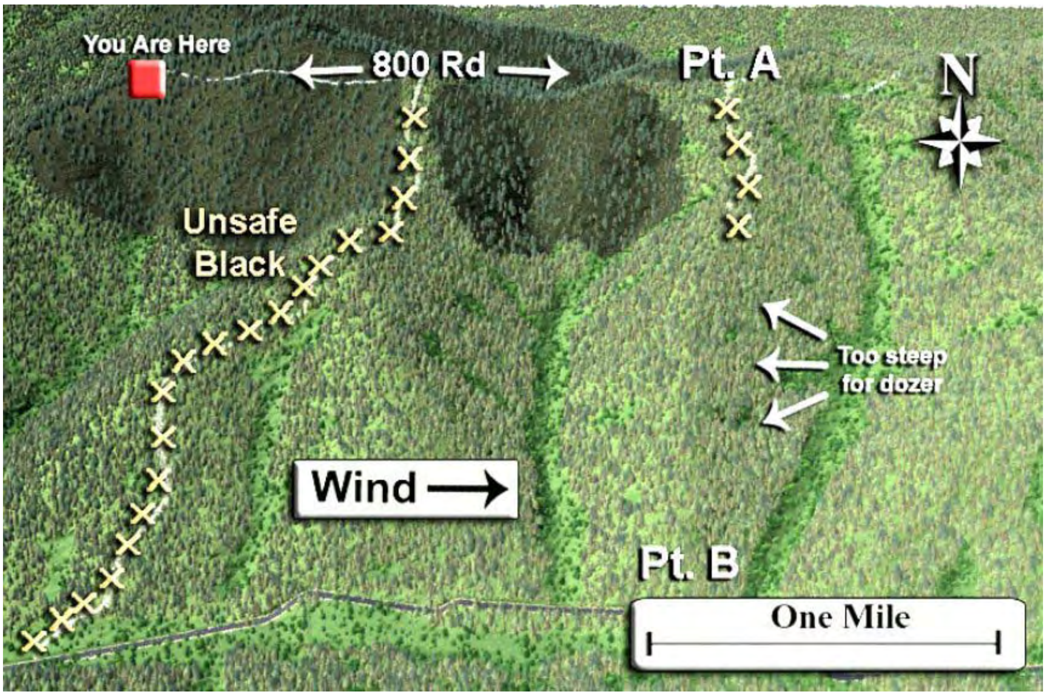


Figure 6: Original paper-based map of a downhill fireline construction exercise

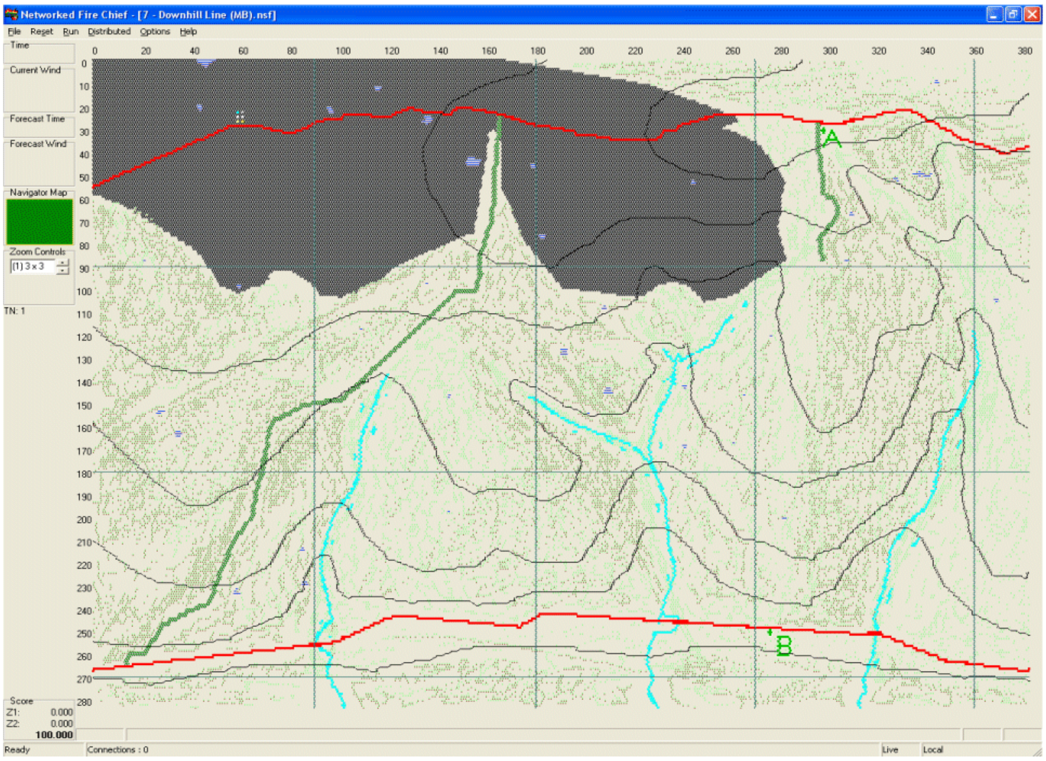


Figure 7: Networked Fire Chief implementation of the same downhill fireline construction exercise

Experimental Manipulation of Mental Workload

Another approach to obtaining scenarios suitable for the experimental investigation of safety-related research hypotheses is to develop specially constructed landscapes with associated fire and wind events. The main advantage of this approach over using only historical fires and existing landscapes to investigate potentially high-risk wildfire situations is that the researcher can achieve tighter experimental control over what is being simulated. Such control is particularly important if one wishes to unambiguously draw causal inferences from the research findings. Here we present two experimental scenarios that are already in use testing specific hypotheses concerning human-factors presumed to underlie safety compromising decision making.

One such scenario has been developed by Ms Pam Sapurmas, La Trobe University (supervisor Dr Mary Omodei) with funding support from a Bushfire CRC Honours Level Scholarship.

The aim of the Sapurmas study is to experimentally manipulate the level of mental workload imposed on research participants so as to investigate the extent to which increases in mental workload lead to changes in attentional behaviour and/or to degradation in overall situation awareness. After extensive practice with a range of Networked Fire Chief scenarios, each participant is given two scenarios similar to those shown Figures 8(a) and 8(b). In both scenarios several fires break out at the start, with two additional fires breaking out somewhat later, one of these later fires posing the greatest threat to housing and therefore requiring immediate attention. The only difference between the two scenarios is that at the time these two additional fires break out the initial fires have a longer perimeter (resulting in a higher mental workload) than in the alternate scenario. Preliminary findings indicate that under conditions of higher mental workload participants are more susceptible to "tunnel vision" with respect to the initial fires, failing to adequately monitor the remainder of the landscape for new fire developments.

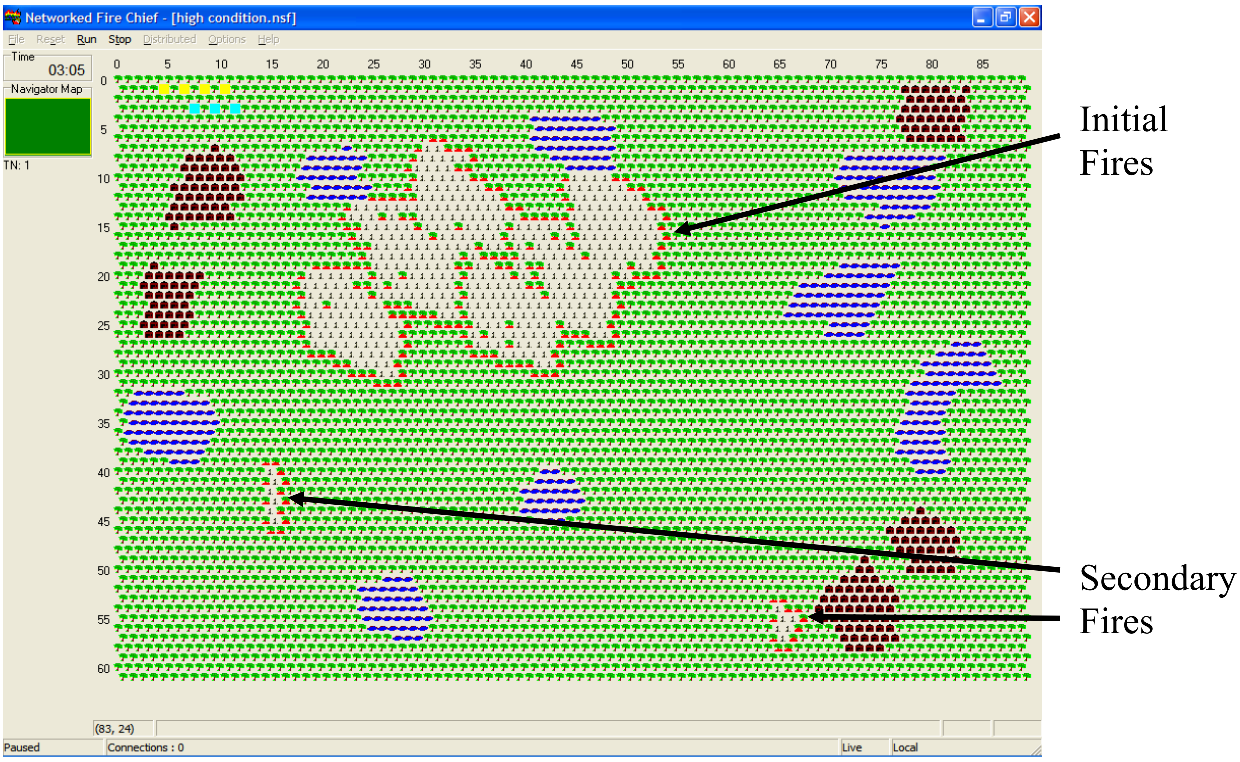


Figure 8 (a) Networked Fire Chief scenario in which secondary fires (the two small fires) ignite when the initial fires have a relatively <u>large</u> perimeter (top left fires).

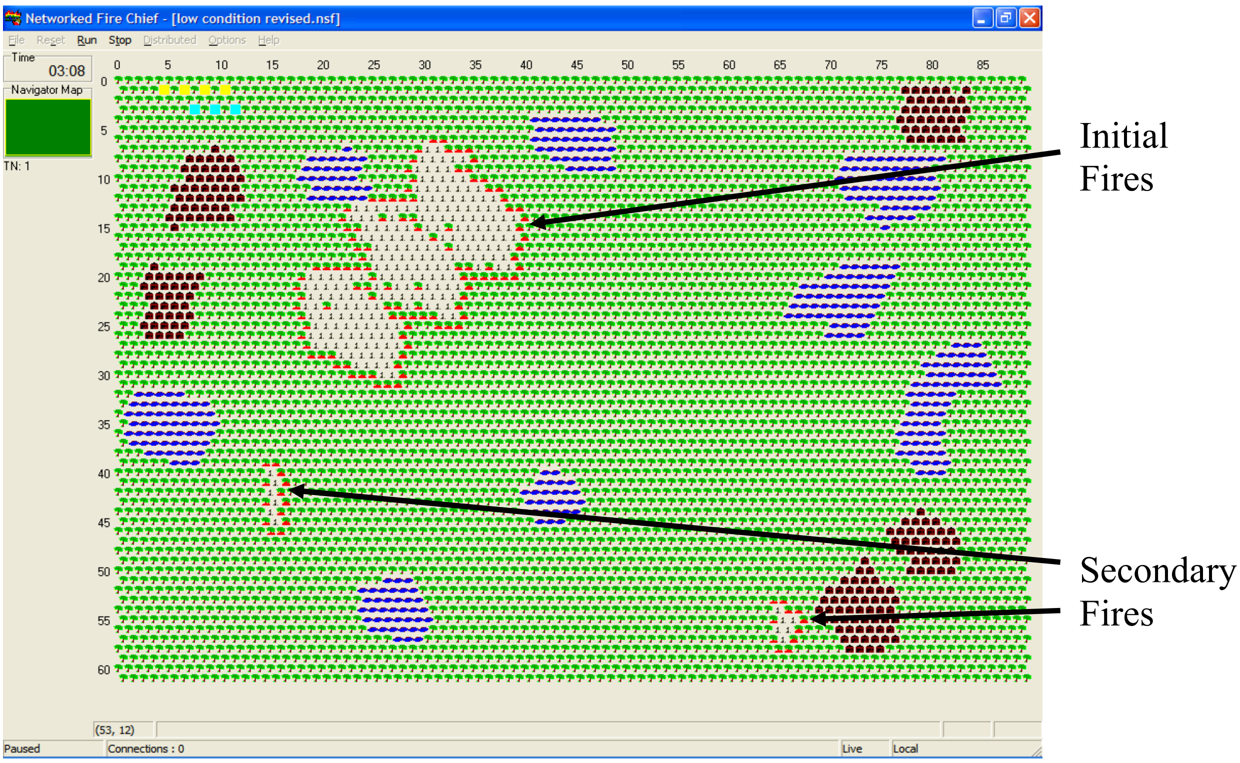


Figure 8 (b) Networked Fire Chief scenario in which secondary fires (the two small fires) ignite when the initial fires have a relatively <u>small</u> perimeter (top left fires).

Experimental Manipulation of Resource Availability

A quite different specially constructed scenario has been developed by Ms Anna Brozovic, also of La Trobe University (supervisor Dr Mary Omodei) with funding support from a Bushfire CRC Honours Level Scholarship.

The aim of the Brozovic study is to investigate the extent to which participants attempt to use more decision resources than they can cognitively (mentally) manage. After extensive practice with a range of Networked Fire Chief scenarios, each participant is given two scenarios similar to those shown Figures 9(a) and 9(b). These scenarios are identical with the exception the participant is provided with 8 fire trucks in one scenario and 16 fire trucks in the alternate scenario. These fire trucks are the only firefighting resources available to the participant for fighting the simulated fires. The characteristics of the fire trucks are such that most participants can only manage 8 fire trucks. Preliminary findings indicate that participants do significantly worse when they have access to the additional resources. It is interesting that one of the findings to emerge concerning the 2003 California (USA) fires was that over-abundance of resources in some locations presented significant management difficulties (Mission Centered Solutions, 2003).

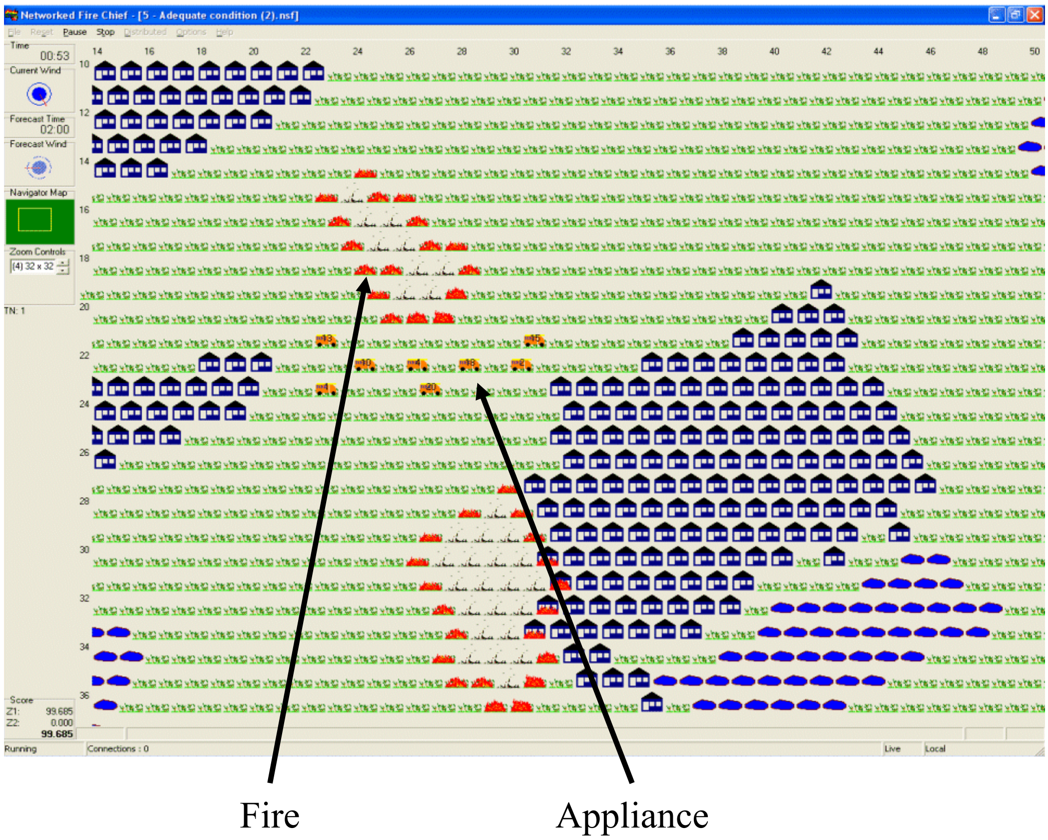


Figure 9 (a) Networked Fire Chief scenario with 8 firefighting appliances

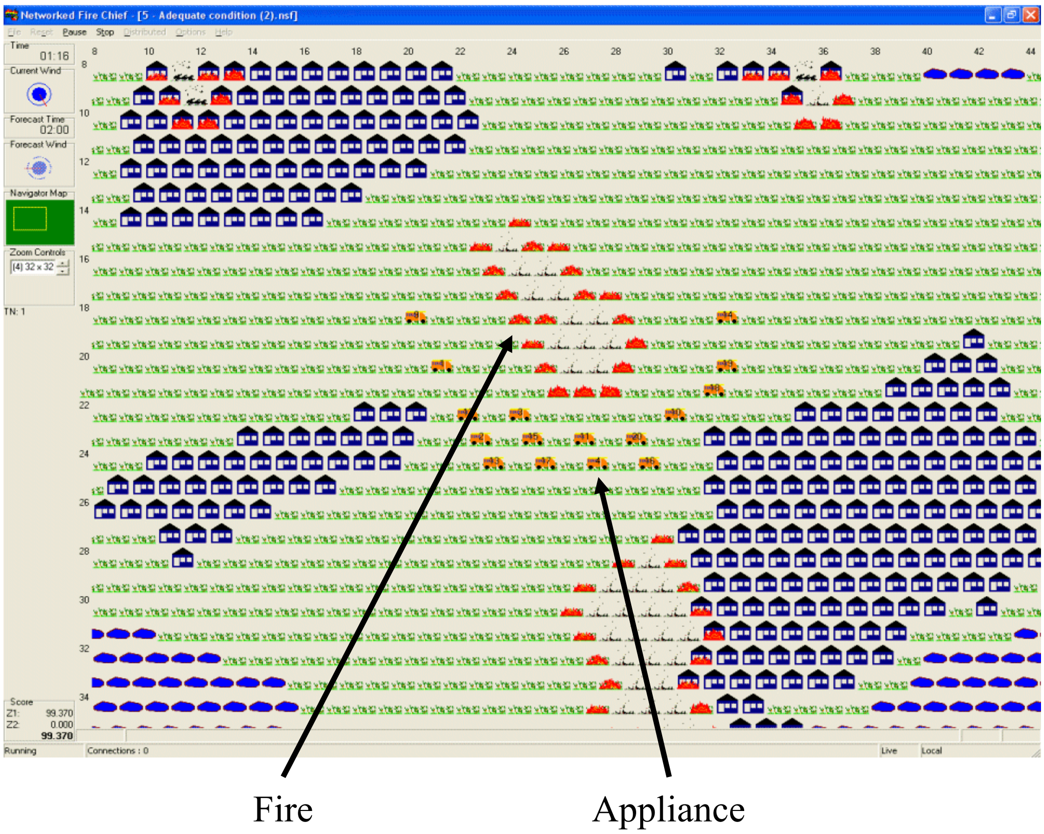


Figure 9 (b) Networked Fire Chief scenario with 16 firefighting appliances

9 Conclusion

The primary aim of the “Enhancing Safety” project is to investigate human factors underlying unsafe decision making in the context of Australian wildland firefighting. Although there is no substitute for timely interviews with firefighters involved in actual incidents to identify such human factors, hypotheses generated from the information provided in such interviews need to be tested by means of tightly controlled experiments in order to evaluate the validity of any interpretations and to unambiguously determine cause and effect relationships.

In reviewing the seven wildland firefighting simulation programs we could locate, we conclude that the Networked Fire Chief wildland firefighting scenario generator is the best, and most cost-effective, simulation tool currently available to create reliable and valid safety-relevant experimental scenarios. Nevertheless, as alternative simulations become available these will be examined for their likely potential to complement the research activity initiated using Networked Fire Chief.

Regardless of which particular wildland firefighing software tool is used to generate experimental scenarios, useful findings concerning safety in wildland firefighting decision making will require close ongoing involvement of fire agency personnel in the development and testing of experimental scenarios.

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Appendix A: Human Factors Checklist

From our reading of the literature on human factors involved in decision making in situations characterised by complexity, uncertainty, and time-pressure, we have identified the following factors as potentially applying to wildland fire fighting.

1. Individual factors
   a. knowledge base (training, understanding of wildfire concepts);
   b. personality (perceived accountability, risk propensity);
   c. cognitive limitations (limitations of working memory);
   d. cognitive biases (risk homeostasis, optimism bias, overconfidence);
   e. cognitive impairment (fatigue, physiological fitness);
   f. motivational (perceived rewards, sanctions);
   g. attitudes (values, expectations).
2. Small-group factors
   a. team/crew cohesion;
   b. team leadership (nominal and actual);
   c. team/crew dynamics.
3. Organisational factors
   a. operational doctrine;
   b. safety culture;
   c. safety climate.

Appendix B: Networked Fire Chief Default Fire Spread Model

A two-part model specifies the development of a fire in the Networked Fire Chief program. One part specifies the development of a fire within a consumable landscape element and the other specifies the progression of the fire to adjacent consumable landscape elements. The model was empirically derived by investigating the ability of equations of various forms to generate fires which would spread in the same way as actual fires are observed to spread.

Part 1. Development of a fire within a screen segment

Two equations model the development of fire within each consumable landscape element for a generation (simulation cycle). Equation 1 calculates the fire intensity and Equation 2 uses this value to calculate the amount of consumable fuel that remains at the end of that generation.

$$F_{ij} = D_{ij} \times R_a \times (0.4 + e^{(W_{ij} + H_{ij}) 1n\, S}) \times (tan^{-1}(Sl_{ij}) \times (1/(20 \times Pi \times 1/180))^2)$$

Equation 1 Fire Intensity

where
F_{ij} = Fire intensity in landscape element ij.
D_{ij} = Density of Consumable Fuel in landscape element ij.
R_a = Fire Spread Rate in landscape element of type a.
W_{ij} = Wind Direction Factor for landscape element ij. This is calculated on the current wind direction and the direction that the fire was ignited from.
H_{ij} = Headfire Adjustment Factor for landscape element ij. This is calculated at ignition time and simulates a fire being ignited in a segment that has been preheated by existing fires.
S = Wind Strength.
Sl_{ij} = Slope (in degrees) for landscape element ij. This is calculated by comparing the elevation of the landscape segment ij with the elevation of the adjacent landscape element from which the fire had spread.

$$C_{ij}(t) = C_{ij}(t-1) - F_{ij}$$

Equation 2 Fuel remaing after time t generations

where
$C_{ij}(t)$ = Consumable Fuel in landscape element ij at time t.
$C_{ij}(t-1)$ = Consumable Fuel in landscape element ij at time t – 1.
F_{ij} = Fire intensity in landscape element ij.

Part 2 Progression of the fire to adjacent screen segments

When the total amount of consumable fuel in a consumable landscape element falls below a minimum specified value (10% of the original fuel), the element is declared to be destroyed and any adjacent consumable elements are declared to be ignited. The following pseudo-code summarises the rules used by Networked Fire Chief to determine progression of the fire to adjacent consumable elements.

```
if Cij < min Cij then
begin
    Fij = 0
    for each adjacent consumable landscape element do
        if Cadjij > 0 then
            Fadjij > 0
end
```

When the total amount of consumable fuel in a landscape element (C_{ij}) falls below the minimum specified value (min C_{ij}), the element is declared to be destroyed ($F_{ij} = 0$) and any consumable landscape element with enough fuel to support the *fire* ($Cadj_{ij} >$ min $Cadj_{ij}$) is declared to be ignited ($Fadj_{ij} > 0$).

Appendix C: Linton/Midlands Fire December 1998

On 2nd December, 1998, five firefighters tragically lost their lives in a burnover incident just North of Linton in Victoria.

The following brief description of the complete incident has been taken from a 1999 CFA report; "Reducing the risk of entrapment in Wildfires: A Case Study of the Linton Fire", page 3.

> "On Wednesday 2 December 1998, at about 13.00 (1.00 p.m.), a wildfire started in forest north of the small Victorian town of Linton. The day was hot (28°C) with light northerly winds.
>
> The Fire was managed by an Incident Management Team consisting of CFA and NRE personnel. An Incident Control Centre was established at the NRE Office in Ballarat and an Operations Point and a Staging Area were established at Linton.
>
> At about 18.00 (6.00 p.m.), when the main fire had been contained around the edge of the town, bulldozers supported by tankers started clearing a control line on the eastern flank of the fire.
>
> At about 20.00 (8.00 p.m.) the Operations Point broadcast a warning to crews that a wind change was one hour away.
>
> Two tankers, one from Geelong City and one from Geelong West drove ahead of a bulldozer along an old track in an attempt to get to a water point. The crews of the two tankers did not acknowledge receipt of the broadcast warning.
>
> The two tankers were surrounded by unburned fuels and were up-slope from the fire.
> When the wind changed direction and strength it drove the fire towards the Geelong City and Geelong West tankers. One tanker was destroyed by fire and its crew of five men died."

We have chosen to simulate this particular area two reasons: (a) We are ourselves familiar with the area, and the events involved in the various stages of this fire, having been contracted to prepare a Human Factors report on the incident for the Coronial Inquiry (McLennan, Omodei, Wearing, 2001; and (b) Many readers of this present report are also likely to be familiar with the fire and associated events, and therefore able to recognize their implementation as a Networked Fire Chief scenario.

Out of respect for those persons who were involved in with the actual fire and associated events (particularly the loss of lives), we have chosen to limit our focus to the first attack phase of the fire. To ensure that we had accurate information, we collected reports on the incident and examined maps of the area. Using available information such as wind reports (both wind strength and directional changes), and geographical terrain information we were able to develop a realistic re-creation of the fire spread. The resultant scenario map showing the fire just after it had spread south across Snake Valley Road is shown in Figure 10. To portray the area with the greatest level of detail, for this map North is to the left side of the screen (in all subsequent scenarios convention is followed in having North to the top of the screen).

We have demonstrated this re-creation to several senior CFA wildfire instructors, who have assured us that the simulated fires do, in fact, behave as the actual Linton fire was reported to have behaved.

The sequence of Figures 11 to 13, demonstrates several stages of the early phase in the Linton fire in which a large direct attack from Snake Valley Road was planned. At the time of the incident the overall size of the fire was still relatively small (see Figure 10), and the plan, if successful, would have contained the fire. At approximately 2.30pm, 27 tankers lined up to stop the fire on Snake Valley Road. From the perspective of the crews in the tankers, the fire would have become visible as it crossed over the spur, moving down towards, and crossing a shallow watercourse just to the North of Snake Valley Road. At this stage the downhill moving fire front was of a low intensity associated with relative low flame heights (an appropriate intensity for a successful direct attack).

However, as shown in Figure 13, the intensity of the fire front, and associated flame heights, increases dramatically as the fire moves rapidly up-slope from the shallow watercourse to nearby Snake Valley Road. In the actual event, the fire crews were unsuccessful in their attempt to contain the fire to the North of Snake Valley Road. The fire jumped the road and continued in a Southerly direction towards the township of Linton.

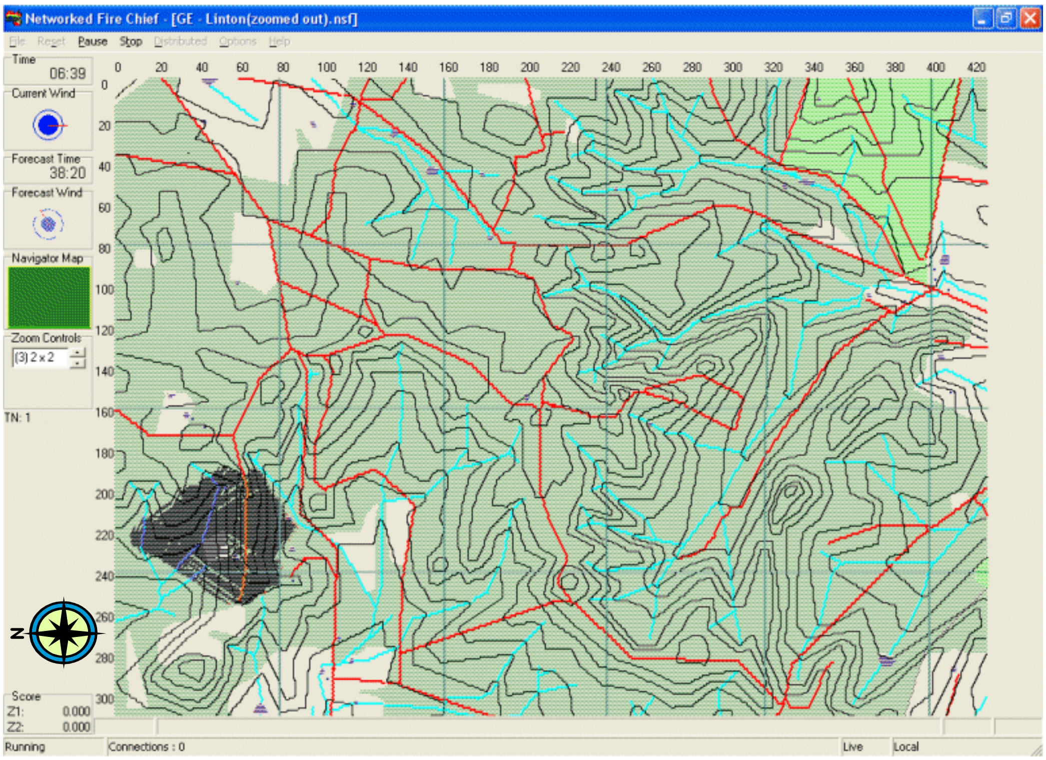


Figure 10: Networked Fire Chief scenario showing a re-creation of the early attack phase of the Linton fire (point of origin on fire on far left of screen)

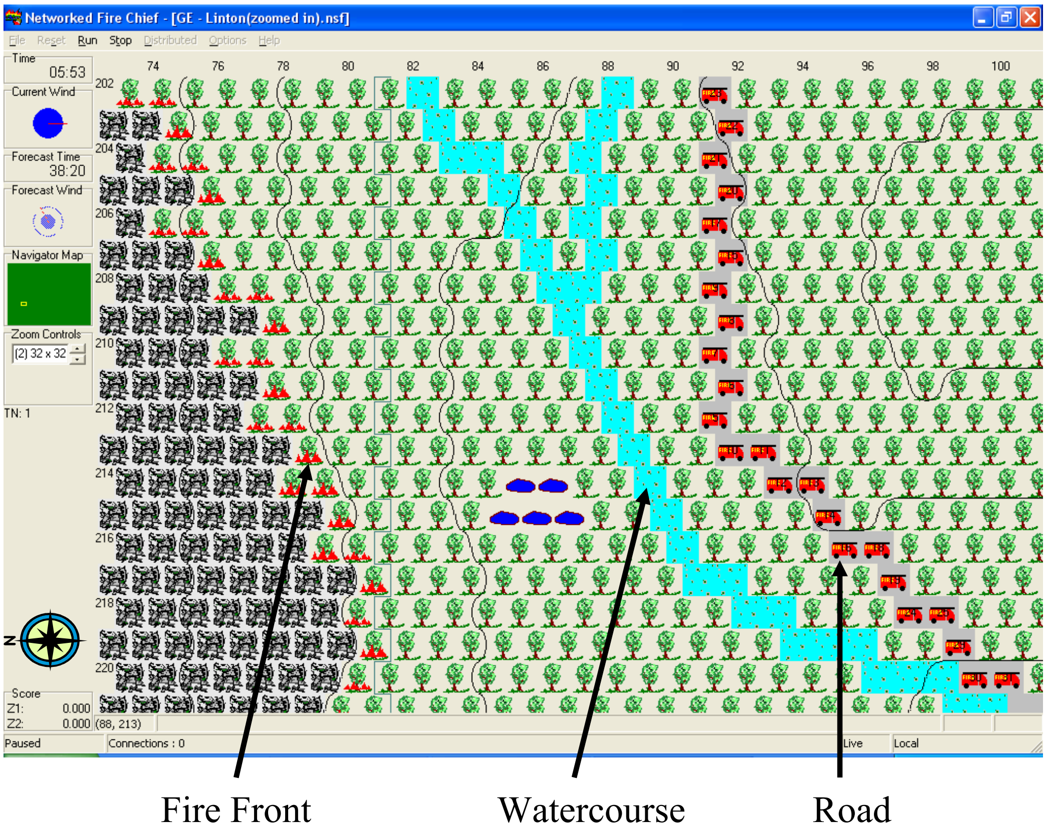


Figure 11. Linton fire moving South towards a shallow watercourse to the North of Snake Valley Road.

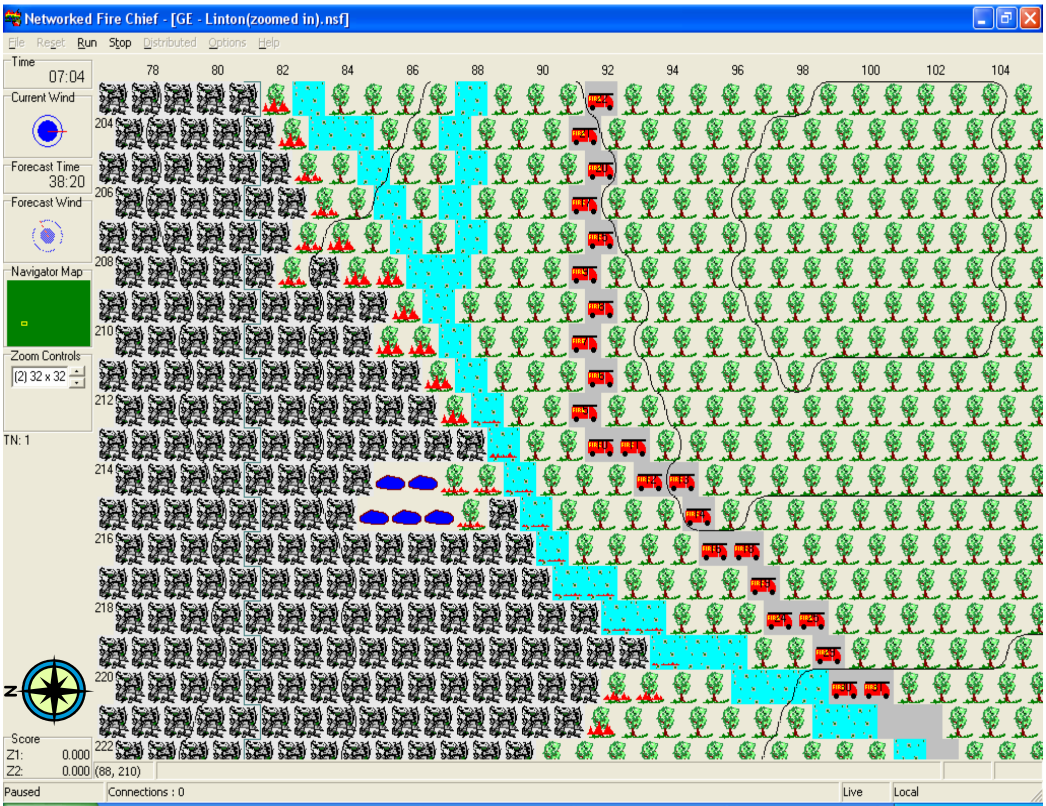


Figure 12. Linton fire front reaches the bottom of a small watercourse just to the North of Snake Valley Road.

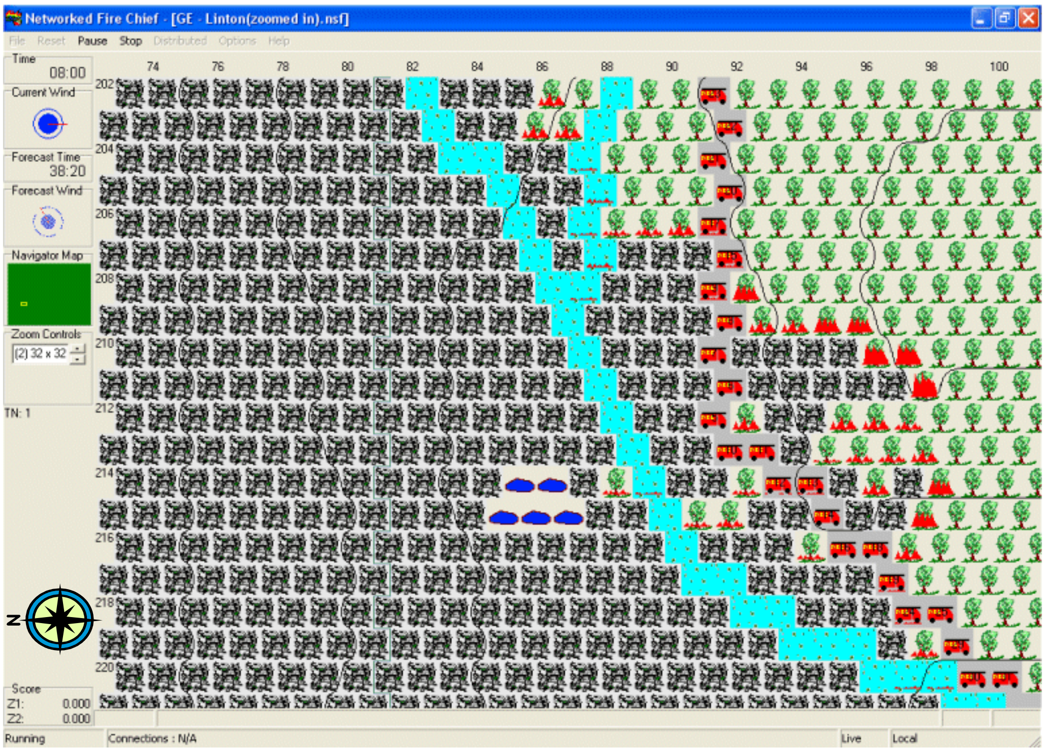


Figure 13: Linton fire front moving up-slope as it crosses Snake Valley Road to the South

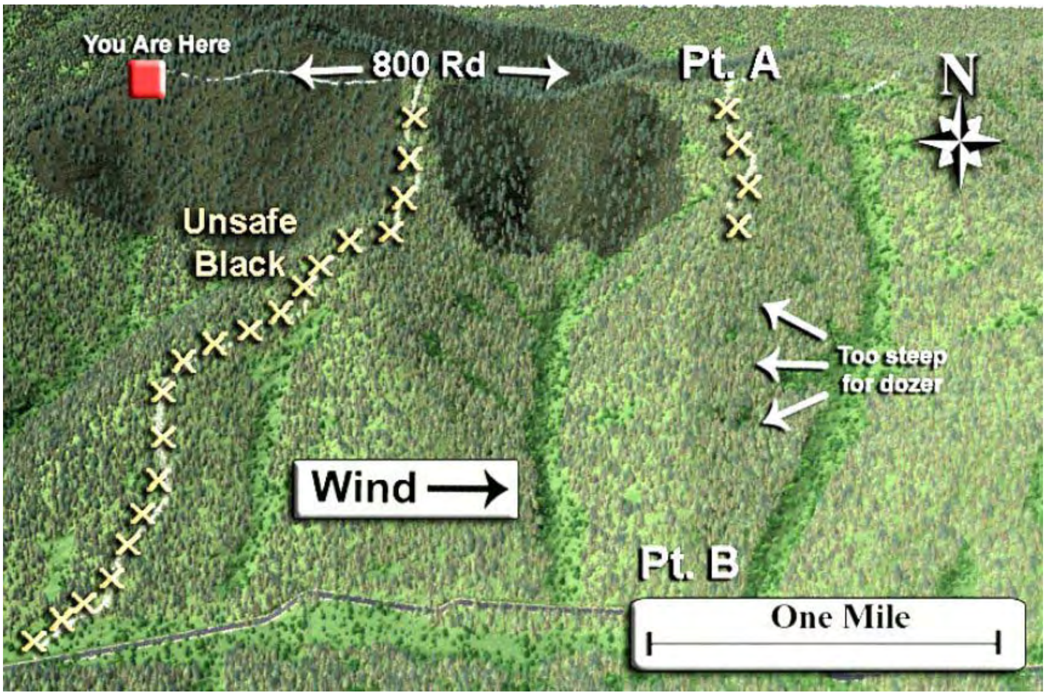
Appendix D: Downhill Fireline Construction Exercise

Paper based training exercises have long been employed by wildland firefighting services. One such paper-based exercise was used to explore the extent to which such exercises could be adapted to the more dynamic task environment afforded by real-time computer simulation. One advantage of presenting such scenarios as dynamic computer simulations is that time pressure can be imposed on *participants*, simulating the sort of time pressures experienced at 'live' fires. In addition to the increased psychological fidelity afforded by such real-time simulation, such simulations also allow for the capture of performance data and for the facility to engage the *participant* in subsequent exercise replays to support detailed analysis and debriefing.

We chose a 'downhill line construction' as the test scenario. This paper-based scenario was sourced from a refresher training guide, "Expect the Unexpected: 2003 Fireline Safety Refresher Training", from the US Bureau of Land Management Office of Fire and Aviation, and can be retrieved at http://www.fire.blm.gov/training/blmtrng/Fireline%20SWB%202003.pdf

Original Paper-Based Exercise

Work Group Task: Your assignment is to complete line construction between Points A and B. Given the listed resources and the Incident Response Pocket Guide (IRPG), how would you accomplish this task? What are your safety concerns and how will you mitigate them. Assume you are currently staged with your available resources on the 800 road. The only safety zone is located off the map ½ mile west of your location.



CURRENT SITUATION:

Date/Time: **December 11, 2002; 0900.**

This fire has been burning for several weeks. On 8/12, a slop-over occurred on your division. High afternoon wind gusts blew fire over the 800 Road. Currently the slop-over is creeping in the understory and is approximately 30-40 acres. The fire north of the 800 Road has been categorized as an "unclean burn" and not acceptable as a safety zone.

Management Objective:

Stop the spread of this fire to the east.

Fuel Type:

Fuel models 9 and 10 (heavy timber and slash with a thick understory).

Weather Recap:

Previously experienced some crown torching up to 200 yards and spotting about ¼ mile after inversion lifted around 1300.

Trigger Points:

RH below 22%; temperatures above 86° F.

Weather Forecast:

Temperatures, 88° F; RH, 21%; NW winds, 4-7 mph in a.m. with afternoon gusts up to 15 mph.

Resources available:

one T1 crew, one T2 crew, one D7 dozer, one D4 Dozer, one helitak as needed

Implementation as a Networked Fire Chief Scenario

The first task was to convert the paper-based map, which was an aerial orthophotomap, without contour lines, into Networked Fire Chief. (The contours were interpreted directly from the photomap into the Networked Fire Chief scenario.). This is shown in Figure 14., with unchecked fire spread behaviour being shown in Figures 15.

The *participant* is asked to complete a line construction between points A and B on the map. They have to keep in mind safety concerns and ways of mitigating such concerns. The *participant* is also informed that the only safety zone is located off the map, ½ mile to the west of their current location.

Using the values provided in the paper-based scenario, the McArthur Forest Fire Danger Meter Mk5 (found at http://www.esb.act.gov.au/firebreak/forest-5.html) was used to obtain an approximate rate of fire spread of 750 m/hr.

To validate this rate of spread, a small fire was programmed to start near the scale at the bottom left of the Networked Fire Chief map and left to run for one-hour. The dozer units were set to move at an average speed of 70 km/hr, and the tanker trucks at an average speed of 90 km/hr (N.B. presently, appliances can only move at a constant speed in Networked Fire Chief).

If the scenario is run for two hours, the advantages of having a dynamic computer-based simulation rather than a paper-based scenario, become apparent: The fire spread activity can be experienced in real time by the *participant*, presenting a greater level of psychological immersion in the simulated scenario, as well as a greater experience of having to make decisions under time-pressure.

In this Networked Fire Chief implementation, participants are able to issue commands to appliances in order to see the outcomes of their decision making process. In the scenario shown in Figure 16, a *participant* has adopted a risky procedure of building the second control line in the immediate path of the fire front. They have also used a second dozer team to clear a line starting from the western-most control line, in an easterly direction to meet up with eastern-control line.

Both dozer teams had tanker support and helitak support was sent to the most intense parts of the eastern-most fire front. Under the programmed environmental conditions, the building of the control line was successful. Had the wind been gustier or a wind change that had not been forecast occurred, (both events being readily incorporated into a Networked Fire Chief scenario), this particular strategy may well have placed the dozer teams at considerable risk of being entrapped.

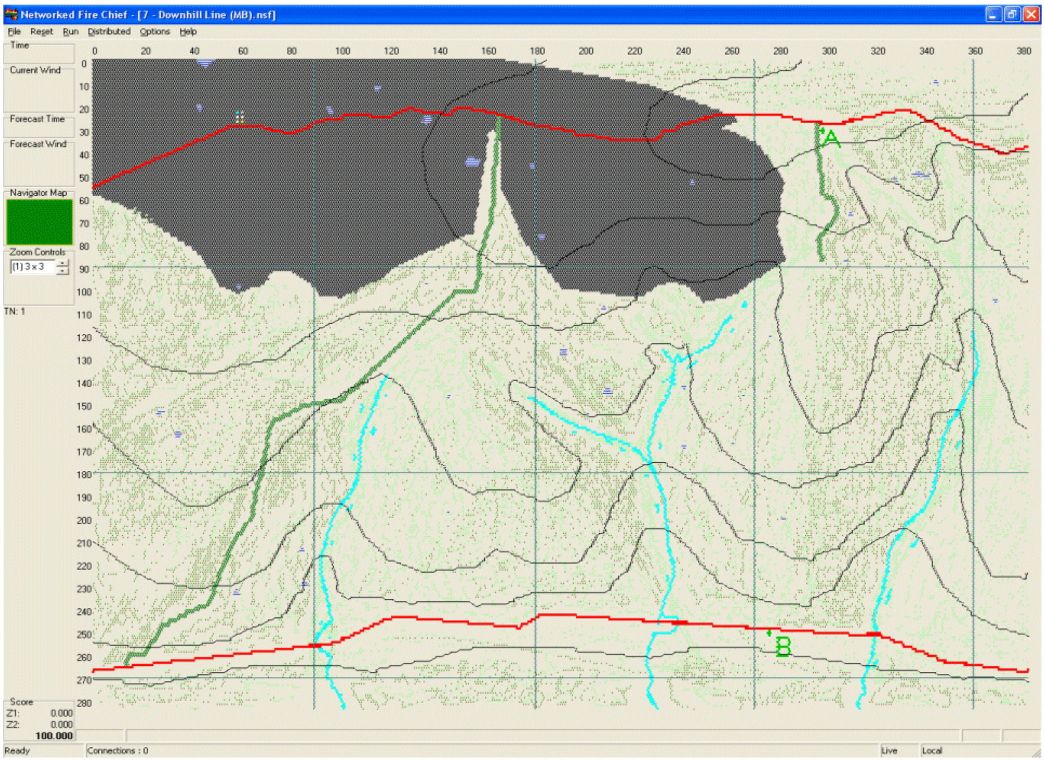


Figure 14 Networked Fire Chief re-creation of original ‘downhill line construction scenario’ map at time 0 minute

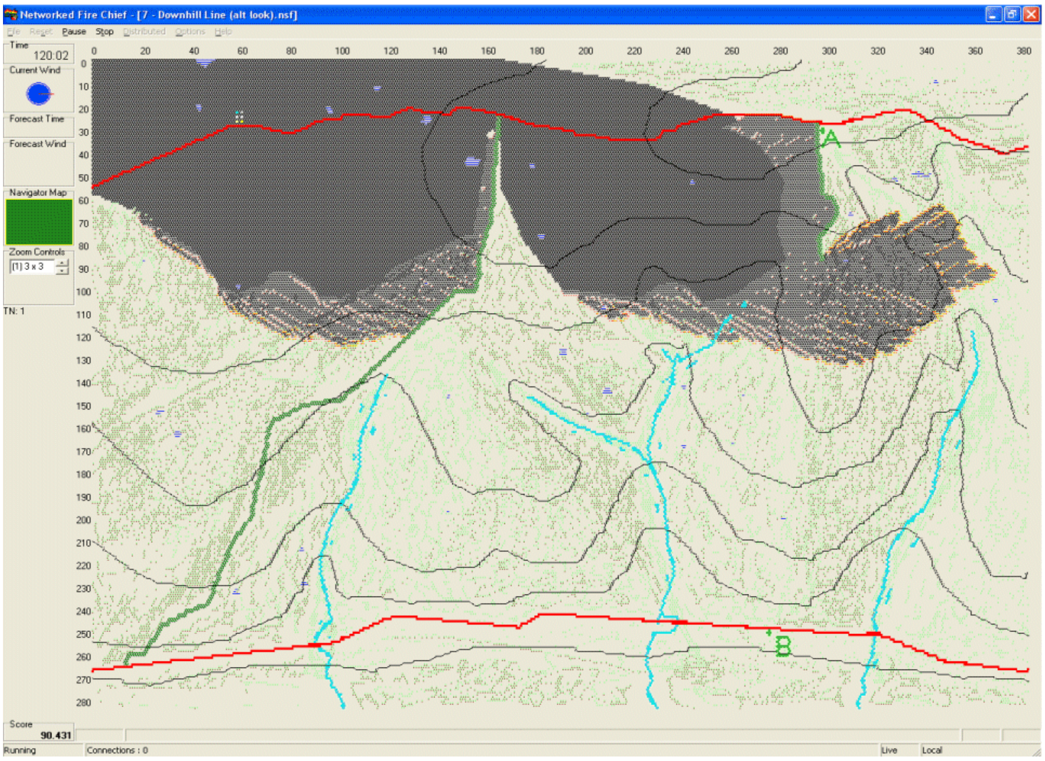


Figure 15: Networked Fire Chief re-creation of original 'downhill line construction scenario' map at time 120 minutes with no participant intervention

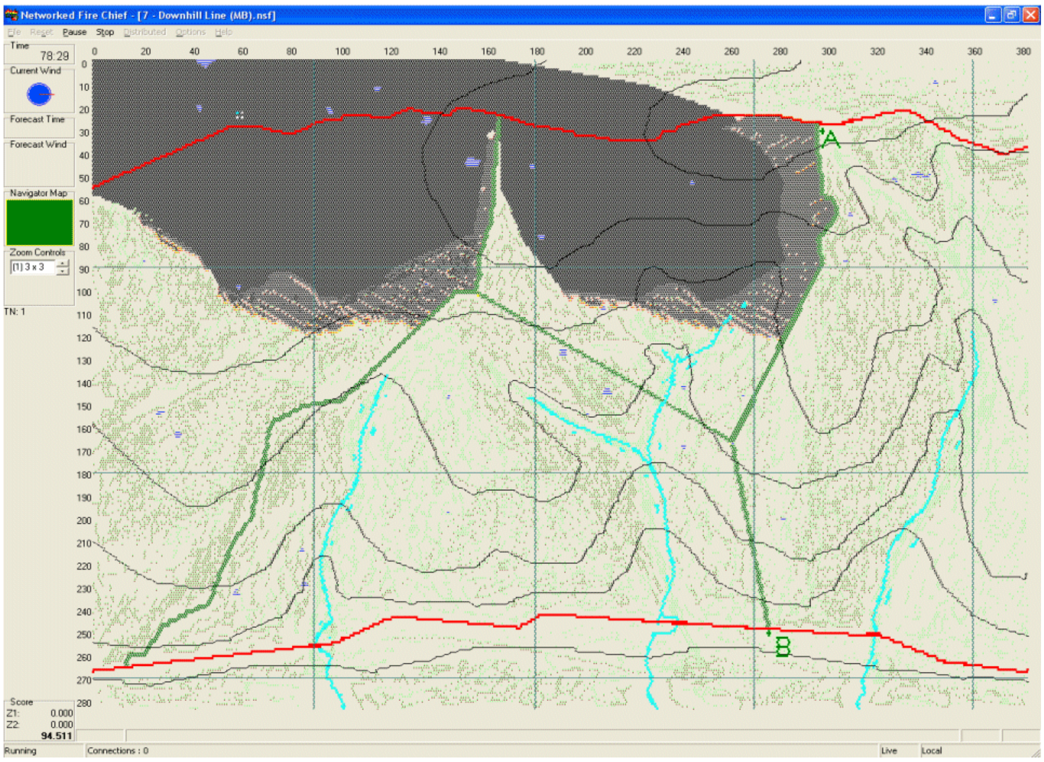


Figure 16: Networked Fire Chief re-creation of original 'downhill line construction scenario' map at time 120 minutes with participant intervention

