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The Future of C2

Title: Informal Communications and Situation Awareness in C2 Environments

Topic: Modelling and Simulation

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Abstract

The paper examines the role of informal information flows and situation awareness in the context of command and control environments for emergency services. The studies are based on investigations into the outcomes for fire brigades dealing with emergencies that exceed their capacity to handle the situations.

The objective of the reported research is to design an approach to the effective and complementary use of both formal and informal information flows to enhance situation awareness, and hence effective decision making, at all levels within an emergency organization.

The case studies of actual and major wild fires illustrated that there were well-defined limits to an organization's capacity to handle the flow of communications, and that there were no strategies in place to cope when these limits were reached. As a consequence a number of ad hoc peer to peer informal communication strategies were adopted by the operational staff. These practically enforced informal flows have an implication that the senior decision makers at headquarters were no longer in the C2 loop.

The paper addresses the reaction of the headquarters to this reality, and proposes a design strategy for a communications network that is a combination of formal and informal flows. This combination is designed to scale seamlessly as the scale of the emergency increases, and is designed to maintain situation awareness at all levels.

Informal Communications and Situation Awareness in C2 Environments

1. Introduction

The effect of using informal channels of communication in demanding operational situations was investigated in the study and modelling of major Australian bush fires in Reference 1. In this paper the original defence oriented problem was transformed to a non-classified environment that of the command and control problems faced in fighting wild fires in southern Australia.

One of the advantages of selecting such an environment is that there are regular opportunities to evaluate concepts and techniques in command and control with reference to a regular and reproducible emergency situation. This is in contrast to the original defence problem area where one hopes it will never occur for real.

The fire environment is no less demanding than many defence environments, and one of the major issues addressed in Reference 1 was the significant effect of the use of informal information on the safety of the fire-fighters. The use of informal information channels enlarged the effective awareness bubble of the operational groups, thus allowing them to make significant decisions as to when to pull out, and where to move to, in a much more timely fashion. One case study is illustrated in Figure 1 where the availability of informal information on an earlier than predicted wind change proved to be crucial to the safety of a group of fire-fighters.

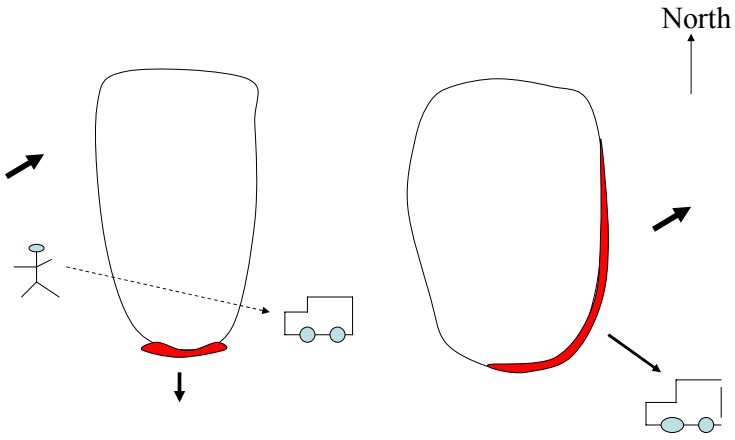

FIGURE 1 WIND CHANGE ALERT

In this use of informal information, the originators of the information were still part of the overall organization, so that the information, though not passing through the formal information hierarchy, was validated, accurate, timely and trusted.

Despite the proven outcomes resulting from the use of informal information in this manner the management of the various fire organizations were opposed to the use of such channels as they were concerned about loss of overall command and control.

This paper covers the investigation into this particular question, and into how a combined informal and formal network can be designed to maintain this expectation of control, with situation awareness being maintained at all levels.

2. The Fire Brigade Investigation

The project into the organizational reactions related to various forms of communication is covered in Reference 2, based on a series of interviews with the Fire Brigade in the Australian Capital Territory, (ACT), following on from the previous referenced work in Victoria. A major reason for working with this Brigade, based in Canberra, was that they had dealt with two very major fires in the previous six years, so that the post-event reports, and staff memories were both available and fresh.

Another reason for working with this Brigade was that they had dealt with a wide range of fire sizes over the six years, from minor scrub fires to the two major wild fires, so that the way in which communications worked, in the context of C2, could be assessed across a complete spectrum of fire emergencies.

The strongly expressed position of the Brigade staff at all levels was that informal communications should not be either available nor used, with a graphical view of the awareness bubbles illustrated in Figure 2, in which all communication is assumed to be formal and hierarchical. This figure illustrates the local awareness bubble for each team, and the overall bubble for the centralised headquarters.

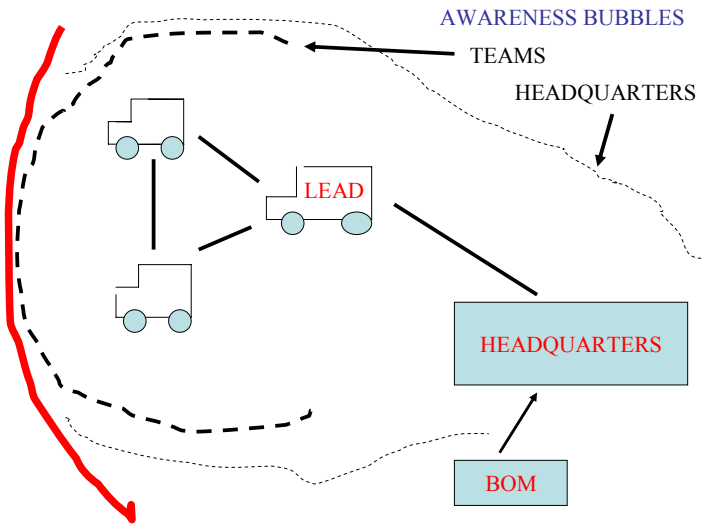

FIGURE 2 AWARENESS BUBBLES LOW LEVEL EVENT

The manner in which the radio network was configured reinforced this viewpoint, with a local group frequency for each team, but with the headquarters monitoring every channel, and hence maintaining a very detailed awareness of the operational situation.

Some of the background rationale for this network configuration was based on:-

- The need to use strict operational formats for messages to ensure clarity and minimise potential misunderstanding.
- To ensure that decision making and subsequent commands came through the central command structure, so overall consistency of operational control was maintained
- The legal aspects would be covered as all command and control messages would be logged centrally and be available for the later and inevitable government enquiries.

In terms of the range of fires encountered by the Brigade this network configuration as presented to the investigators was effective for the majority of fires that occurred. However two aspects emerged form the investigation that needed to be pursued. The first was the discovery that a significant amount of informal communication did in fact take place.

As one example, the informal handover at the end of a shift of fire-fighting between teams was, as in a hospital ward environment, seen as both effective and essential. The information contained in the handover was not logged formally, a further inconsistency as related to the rationale for the hierarchical network design.

Of more importance was the observation that, once an emergency reached a certain size, then the network communication configuration failed, and the Brigade lost control of the overall situation. This was the outcome for the C2 system as observed in the two wild fire events.

This dichotomy was recognised by the Brigade; their absolute requirement for a central hierarchy of communication matched with a recognition that it would fail for major emergencies. The consequences following on from this dichotomy are covered in the next section.

3. The Escalation of an Emergency

Given the range and frequency of different fires, basic economics dictate the sizing of a Brigade's capabilities. It would be unreasonable to size the networks to handle the demand of a major wild fire, based on the statistics that predict a relatively low frequency of such fires.

As a consequence there are a number of characteristics of any Brigade:-

- The existing resources will be too small to handle a major fire event.
- The timescales on which a wild fire escalates precludes upgrading the Brigade headquarter's resources during the event
- Loss of control is predictable, primarily through loss of awareness, and through the significant delays in control information flow to the operational groups.
- There does not appear to be any well-formed strategy for handling this escalation and the associated maintenance of overall control.

During the investigation these characteristics were raised and it was noted that the information flows did change, in some cases totally bypassing lines of command, but this was not a planned outcome. The awareness bubble for the headquarters essentially shrunk as shown in Figure 3 as the rapidly increasing message load saturated the resources. A rough

figure for the message rate for the last and devastating wild fire in the ACT was that the message rate reached a factor of 10* that of the central capability.

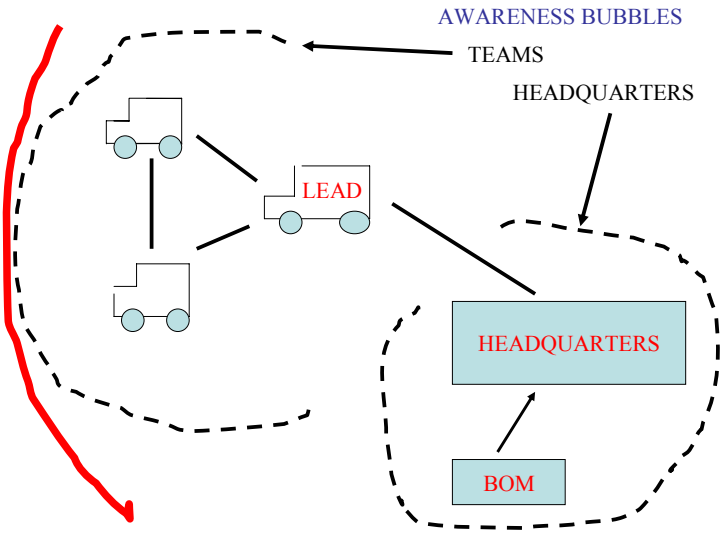

FIGURE 3 AWARENESS BUBBLES HIGH LEVEL EVENT

The outcome from this stage of the investigation was not a criticism of the Brigade, but a clear recognition that there had to be some way in which the inevitable escalation in C2 requirements due to the wild fires rapid growth could be managed successfully.

One starting point is the set of similar problems faced in telecommunications that have been solved in the communications industry. The design of any form of telecommunications switch incorporates a contractual requirement for handling massive overloads, as described in the paper on the Ericsson AXD 301 ATM switch, Reference 3.

The resulting behaviour of the switch as load increases is shown in Figure 4, with loads up to an order of magnitude higher than the normal maximum load. The slow degradation in throughput as the load increases is primarily due to a small overhead in actually rejecting messages.

The figure shows that, if the offered load is 10* the normal maximum, then 60% of the offered load is rejected, and 40% accepted.

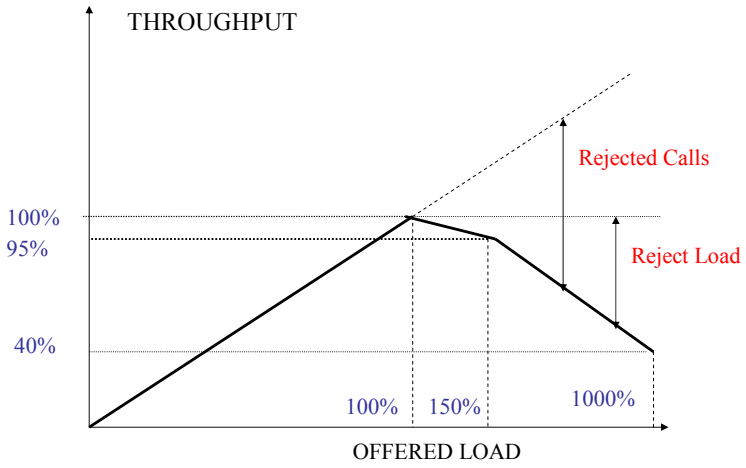

FIGURE 4 NETWORK DESIGN FOR CALL THROUGHPUT

A primary difference between this load shedding behaviour, and that required by a headquarters, is that each incoming message has the same weight or priority, so it does not matter which messages are rejected. In the fire situation in is desirable that the 40% of messages that are admitted to the headquarters are the strategic priority ones, which means that headquarters must accept that a form of priority must exist, listening to every radio call is not an option. Neither is the often used military option of marking every message with a Flash priority.

A further consideration is that the figure of 40% was for a planned strategy for handling the increase in offered load. In the case of the fire brigades a design point of 10% is more realistic.

The investigation then came up with the two core issues, how to ensure that the headquarters moved from micro managing an emergency to an overall strategic role, and how to cope with the 90% of the operational messages that could not and need not be dealt with centrally.

4. The Network Configuration

There are two observations on the scope of the communication network for a major emergency, the first is that the number of operational units does increase, with additional equipment being sought from other states in the case of the ACT wild fires The second is the increasing availability of operational sensors such as unmanned aircraft, or UAVs

The implication from these two observations is that the overall configuration of the network can handle the message load if and only if informal communications are permitted, and that direct operational sensing information can be made directly to the operational groups, as shown in Figures 2, 3 and 5.

The simulations covered in Reference 4 of major case studies of actual wild-fires showed examples of such interactions where the informal network comprised a set of peer to peer communications that were both timely and effective. The information communicated, such as

a wind shift or the existence of a new spot fire were also relayed to head office, so that an overall awareness was maintained, but the decision making for critical events had to be made within the expanded awareness bubble of an operational group. The methods, by which such decisions are made within an awareness bubble are explored in Reference 5 by Gary Klein. This use of informal peer to peer communication within the organization was also noted in Reference 6, where very similar issues arose in the Iraq conflict.

The widespread usage of personal Motorola radios in Bosnia, and the use of cellular phones in Iraq, reinforce the viewpoint of the critical nature of the informal networks.

The essence of the network configuration is therefore the potential for any member of the organization to communicate operational information to any other member, but specifically on a peer to peer basis.

This required capability has been explored through the use of a combination of GSM cellular phones integrated with a GPS capability, firstly through the use of GSM base stations as a part of the operations teams, Reference 7, and through the prototyping of a handheld device of similar physical size to the Nokia 9300, that combined a full moving map GPS together with the GSM phone, Reference 8 The network configuration is shown in Figure 5.

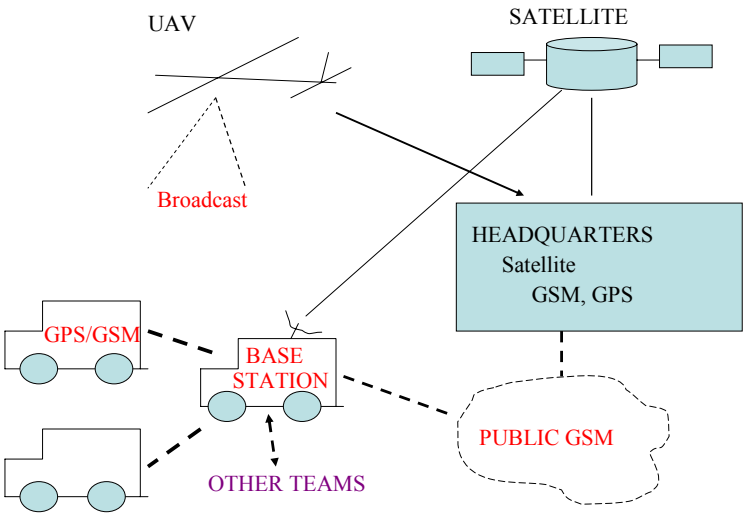

FIGURE 5 CENTRALISED PLUS PEER TO PEER NETWORKS

This network design includes a GSM data messaging capability to be used in place of voice, though the voice capability is retained. The use of a combination of GPS and data links was the last resort for control and communication noted in Reference 9 as an example, which reinforces the viability of this network approach under heavy load conditions.

The primary advantage of the GSM or similar commodity cellular network designs is that they are extremely flexible, and they can be integrated with the public networks, which has a major implication for accessing both members of the public, for such functions as evacuation warnings, and also other emergency service, particularly ones from interstate.

It is interesting that the GPS/GSM approach to network configurations is now a feature of many luxury cars, informing the supplier when an accident has occurred, where it is, and the scale of damage, even before the ambulance arrives. In contrast the Fire Brigades have decided to restrict their communications to voice radio and to the use of the UHF frequency band. This move away from a minimal VHF capability appears to be a retrograde step.

The resulting mesh network design that resulted from the studies is based on the use of enabling technologies for the operational units that permit a greatly enhanced level of situation awareness, and a level of operational decision-making that can be maintained as a wild fire develops. These technologies are now widely available, and, at a personal level, combine GPS moving map and cellular phone technologies, with data as an intrinsic feature.

5. Extensions

The original defence related problems that prompted the projects into the command and control aspects of the fire services are closely related in their characteristics, such as rapid escalation in the size of the problem, and in the communications overload that drastically effects C2 capability.

The primary characteristics that are common across the defence and emergency services is a need for a considerable degree of autonomy for the operational teams, and for a communications network that is robust in terms of load, breakdown or loss of a channel.

Some of these problems come from the space probe domain, where autonomy is not an option, it has to be designed in, and the lessons of the essential need for multiple communications channels have been learnt the hard way.

However one of the most interesting and relevant domains is that of combat UAVs, as featured in Reference 10. The inter-working and communication under uncertainty that is routine in the emergency services domain is very much the problem domain faced by the systems of systems designs envisaged for the combat UAV developments.

Even basic aspects such as bit error rates are of major concern to both domains, for example thick smoke has a high degree of opacity at some of the emergency radio frequencies used in Australia, rendering even basic communications problematic.

As with the fire brigade examples, one of the design issues for the UAV environment is designing an overall architecture that is not inherently headquarters centric, but permits the informal communications to be utilised in an effective manner as communication loads and other problems emerge.

6. Summary

This paper has explored the information gained from interviews with the ACT Fire Brigade to determine their approach to command and control across a range of fires, from local to wild-fires, specifically regarding the use of formal and informal communication channels.

The fundamental conclusion was that the Brigade did not wish any member of the organization to use other than the formal channels, using well-structured voice messages.

However, in practical terms informal information was passed on a peer to peer basis by such activities as team handover at the end of a shift.

Of more importance was the recognition by the Brigade that this approach to command and control, based on the need for total and detailed situation awareness at headquarters, did not allow for the scaling of communications that was essential to handling the relatively infrequent wild-fires. If the situation arose in which a wild-fire occurred, as has happened twice in the last six years, the Brigade would lose control.

The investigations did not find a way of resolving this apparent dichotomy in the C2 approach of the Brigade, but did attempt to find a design approach that would reconcile the overall C2 requirements for an escalating emergency, based on an underlying peer to peer informal network design.

The proposed enabling technologies for such a design incorporate GPS location together with commodity voice and data links, which are currently available and cost effective technologies.
These technologies then permit the current modes of operation of the Brigade, with the ability to extend peer to peer informal communications as an emergency escalates, in an effective and cooperative fashion. Extensions in related domains include the deployment of UAVs within the emergency services domains, such as fire-fighting, and for combat purposes.

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