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Conceptual Design for Resilience

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Outline

- Introduction
- Background
- Approach
  - Command and Control
  - Modeling the C2 Structure
  - C2 Analysis
- Conclusions and Next Steps

Introduction

- With the warming earth's climate bushfires are, and will continue to be, an ever-increasing problem for society in bushfire prone countries like Australia and the United States of America

- The need to enhance society's resilience to bushfires is therefore becoming more prominent

- The aim of this research described in this paper is to increase the fidelity of this preliminary research by focusing in on a key aspect of the 14 design principles of resilience and testing that fidelity in an analytical experiment

Bushfire Response

- The Australian Royal Commission into National Natural Disaster Arrangements (COA, 2020) identified recommendations that cover many aspects, with a number focusing on the Command and Control (C2) aspects of resilience

- This provided motivation to evaluate C2 from a resilience perspective using Model Based Conceptual Design (MBCD) principles
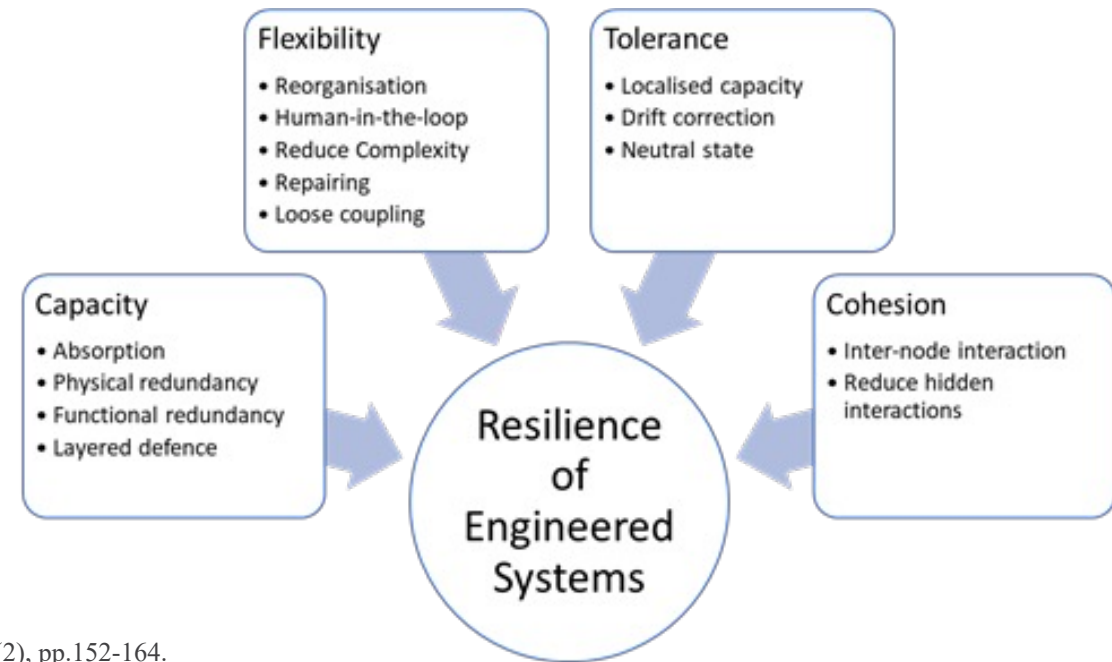
Bushfire Response

- We examined the Australasian Inter-Service Incident Management System (AIIMS), which is Australia's nationally recognized system for incident management. This serves to perform five functional areas, with Command and Control prominent throughout each functional area:
  - **Control** - The management of all activities necessary for the resolution of an incident.
  - **Planning** - The collection and analysis of information and the development of plans for the resolution of an incident.
  - **Public Information** - Provision of warnings, information and advice to the public and liaison with the media and affected communities.
  - **Operations** - The tasking and application of resources to achieve resolution of an incident.
  - **Logistics** - The acquisition and provision of human and physical resources, facilities, services and materials to support achievement of incident objectives.

Command and Control for Resilience

- We leverage Jackson and Ferris 14 design principles of resilience, and consider 3 main principles for C2 against bushfires:
  - Human-in-the-loop
  - Reorganisation
  - Internode Interaction

Flexibility
- Reorganisation
- Human-in-the-loop
- Reduce Complexity
- Repairing
- Loose coupling

Tolerance
- Localised capacity
- Drift correction
- Neutral state

Capacity
- Absorption
- Physical redundancy
- Functional redundancy
- Layered defence

Cohesion
- Inter-node interaction
- Reduce hidden interactions

Resilience of Engineered Systems

Jackson, S. and Ferris, T.L., 2013. Resilience principles for engineered systems. Systems Engineering, 16(2), pp.152-164.

Command and Control Design Considerations

- There are, according to Albert and Hayes (2006), three critical factors, or dimensions that should be considered that define the principles of C2. These are:
  - **Allocation of decision rights** – who has the responsibility for decisions
    - Humans can provide decision making to identify and deal with unforeseen situations and adapt in response
  - **Patterns of interaction among the actors** – the network of actors, including both C2 nodes and other systems
    - This ensures that each node can cooperate and collaborate with every other node, remain informed, and understand the situation
  - **Distribution of information** – the information that is disseminated across the system
    - Ensures the right information is sent to the right node at the right time, and can enable restructuring to respond to the bushfire

Enhancing C2 Design

- Albert and Hayes (2006) argue that C2 should trend towards "edge organizations" and away from the "classic C2"
- We are motivated to explore C2 and bushfire resilience in these areas

- Can model-based Conceptual Design enable the abstract concept of C2 for resilience to be explored in the conceptual design of bushfire response systems
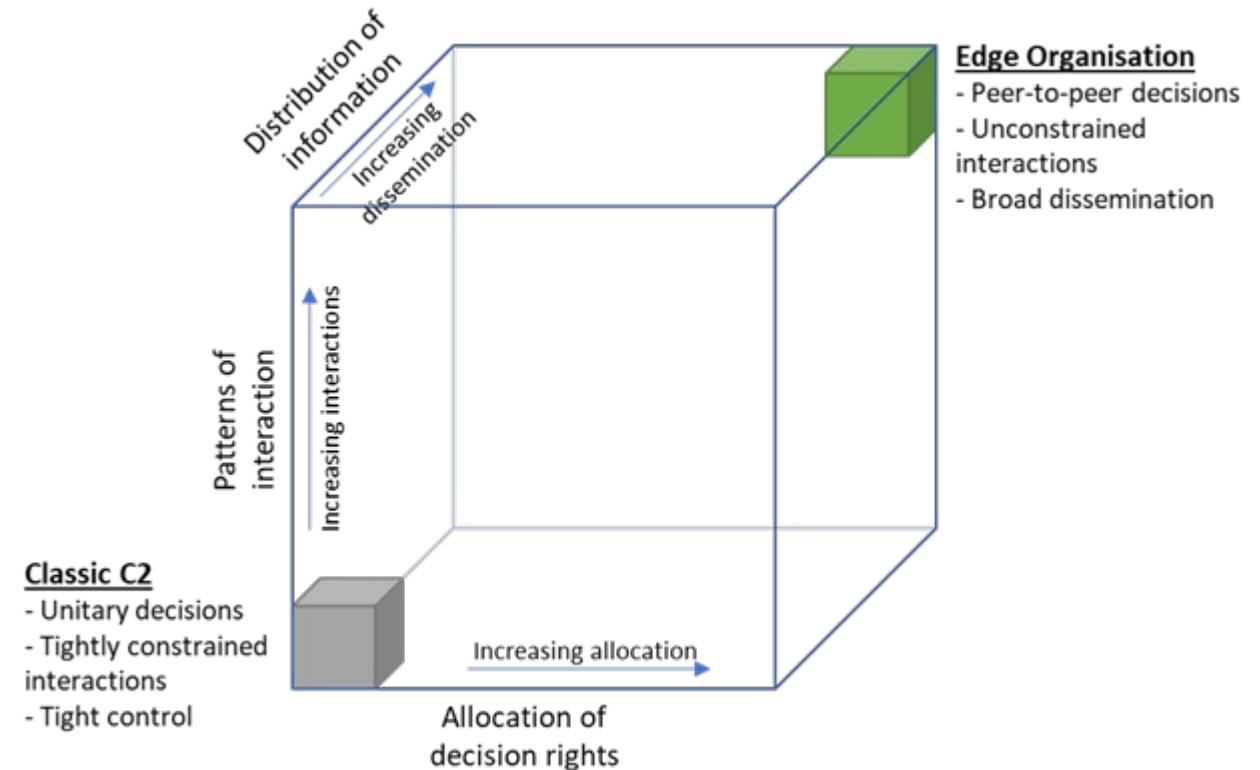

Alberts, D. S., & Hayes, R. E. (2006). Understanding command and control. Assistant Secretary of Defense (C3I/Command Control Research Program) Washington DC, 2006.

MBCD Construct

- This is a previous MBCD construct to look at the operational, system, and test domains
- We can agree that this is still valid to represent C2 functionality
- We are interested in the construct validity if different types of disasters are exercised
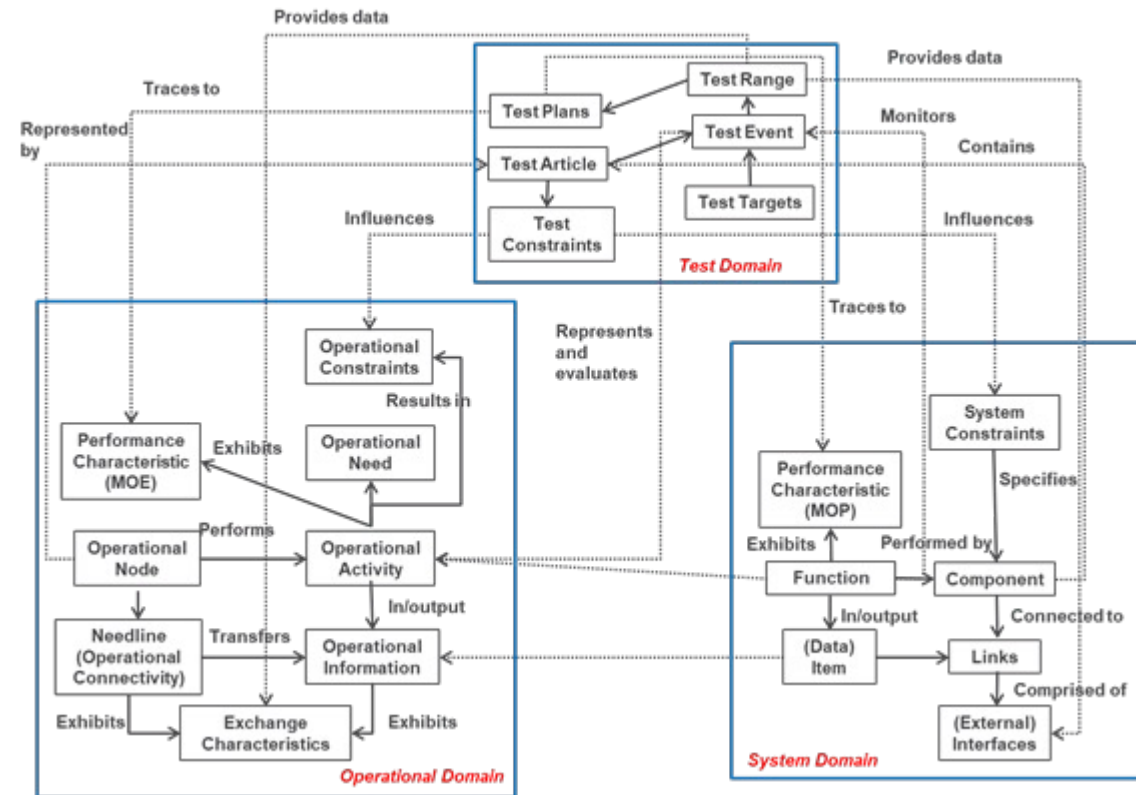
Flanigan, D. and Robinson, K., 2019, July. Exploring the Test and Evaluation Space using Model Based Conceptual Design (MBCD) Techniques. In INCOSE International Symposium (Vol. 29, No. 1, pp. 1072-1083).

Designing for C2 Resilience through MBCD

- We can map our resilience principles to our MBCD schema as well as the C2 approach space
- We are interested if the experiments on the C2 structure can affect the resilience principles

Table 2: Experiment Outcomes

Resilience Design Principle	MBCD Schema	C2 Approach Space
human-in-the-loop	Operational Node	Allocation of decision rights
reorganisation	Operational architecture implemented through Operation Nodes and Needlines	Pattern of interaction/allocation of decision rights
internode interaction	Operational Information / Operational Needline	Pattern of interaction

Modeling the C2 Structure

- We utilize the US National Park Service five levels of incident command systems (National Park Service, 2021) to describe complexity of bushfire situations, with 5 as the least complex, and 1 as the most complex, in order to vary the complexity and evaluate our C2 structure using a bushfire as an example.

  - Type 5 is a very small bushfire, with few resources assigned (less than 6 people) and little complexity.
  - Type 4 is an initial response to the incident and few resources assigned (single team).
  - Type 3 is an extended initial attack on bushfire, requiring several task forces and requires some command staff positions.
  - Type 2 is a major fire with a large number of resources used.
  - Type 1 is a large complex incident requiring multi-agencies and national resources with a large number of personnel and equipment.

Analyzing the C2 with a Notional Example

- This provides a view of the five types of situations that are modeled
- We can include:
  - Situation start
  - Decision maker
  - Bushfire fighting teams
  - Situation end

Situation 5: Least Complex

Situation 4: Initial Response

Situation 3: Extended Response

Situation 2: Complex Problem

Situation 1: Large Complex Problem

Start node   Decision maker   EM Teams   Stop node
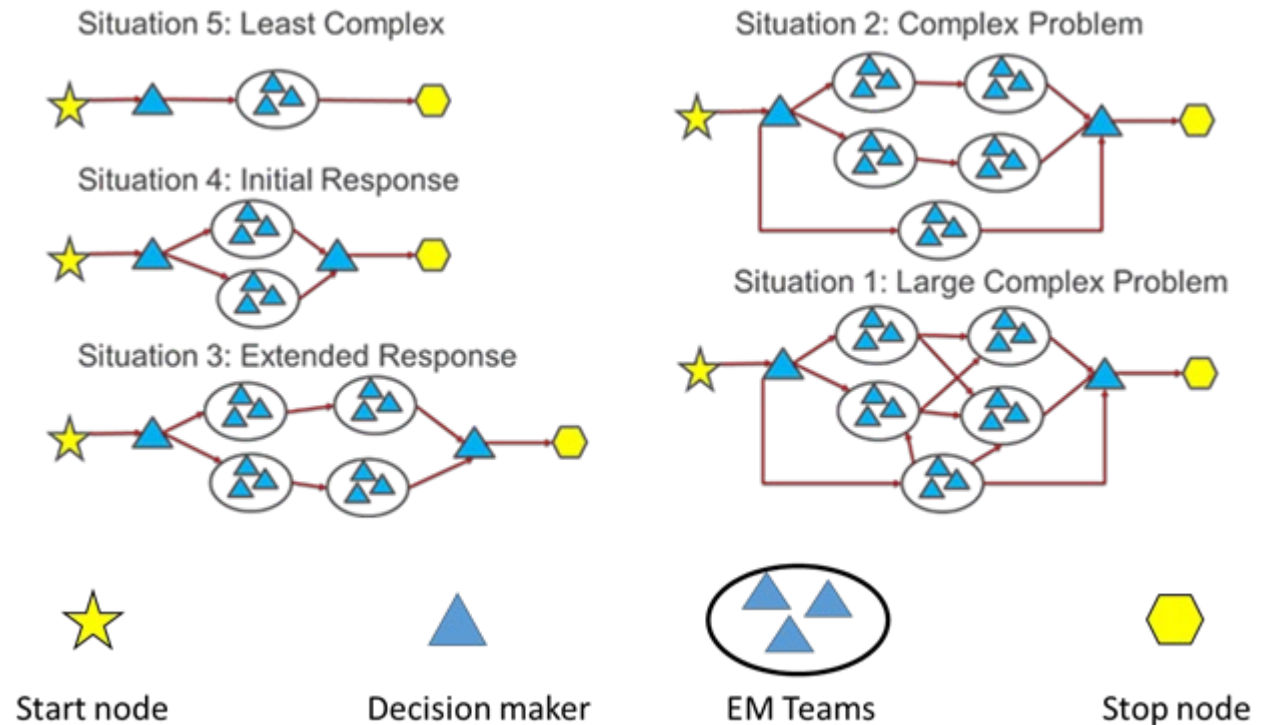
Five Types of C2 Structures

Situation 5: Least Complex	Allocation of decision rights	Patterns of interaction among the actors	Distribution of information
Control	Centralized decision making	Decisions and feedback shared within team	Direct communications within team; no true hierarchy
Planning	Centralized planning	Planning results shared with team	Planning details provided directly to team
Public Information	None until event is over	None until event is over	None until event is over
Operations	Locally controlled within team	Direct tasking within team	Direct communications within team
Logistics	Not needed; self-sufficient within team	Direct coordination within team for resources	Distributed within team

Situation 1: Large Complex Problem	Allocation of decision rights	Patterns of interaction among the actors	Distribution of information
Control	Decentralized C2 across different areas of disaster; different hierarchical levels	Complex interactions, may be overlapping and/or contradictory	Multiple lines of communications
Planning	Multiple planning cells dependent on domain	Complex planning required to deconflict teams	Multiple lines of communications
Public Information	Numerous public information sources	Real-time, and asynchronous updates	Continual updates to public; national attention
Operations	Multiple operations lines	Coordination between numerous teams	May be direct and distributed communications
Logistics	Multiple logistics lines	Interactions across large areas for specific logistics items	Complex logistics information

- These are examples of two situations
- For each of the situations we want to evaluate the 5 levels, and answer the 3 topics

C2 Structure Analysis Approach

- For each of the situations, we utilize a different C2 structure for bushfire fighting

- Our experiment starts with randomly degrading nodes, and then seeing the cascading effects throughout the rest of the C2 structure, based on the hierarchy and connectivity

- We postulate that structures with more complexity and interdependency would fare worse when more nodes were degraded, and potentially lower level nodes may not have a strategic view of the firefighting problem, and focus on localized details

Situation 5 (Least Complex) Analysis

10% node degradation

Decision maker:
Not affected

EM Teams:
No degradation

20% node degradation

Decision maker:
Not affected

EM Teams:
Some degradation

30% node degradation

Decision maker:
Not affected

EM Teams:
Minimal degradation

No nodes affected

This node affected

This node affected
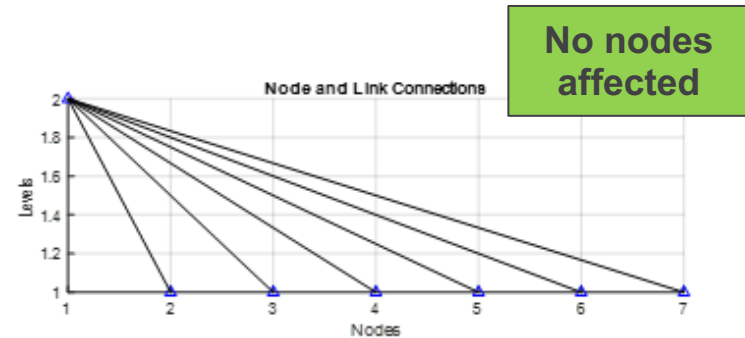
% Level 1 nodes unaffected

% Level 2 nodes unaffected
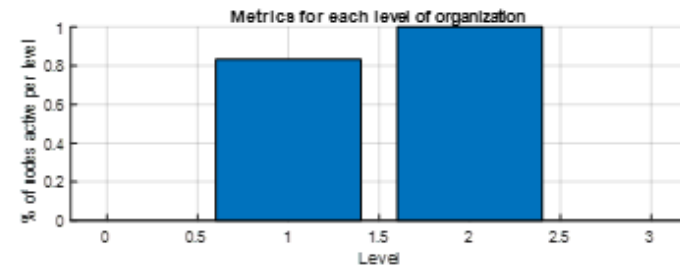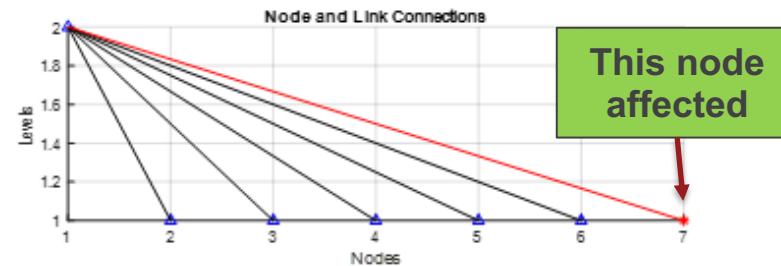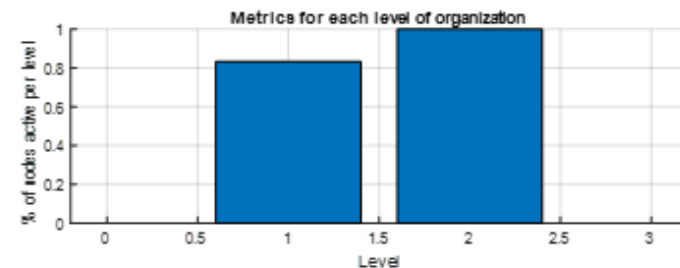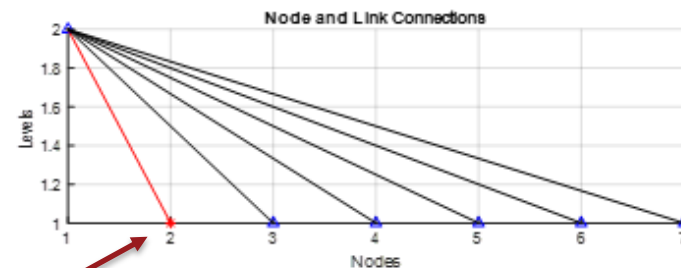
Situation 4 (Initial Response) Analysis

10%

Decision maker:
Not affected

EM Teams:
Minimal degradation
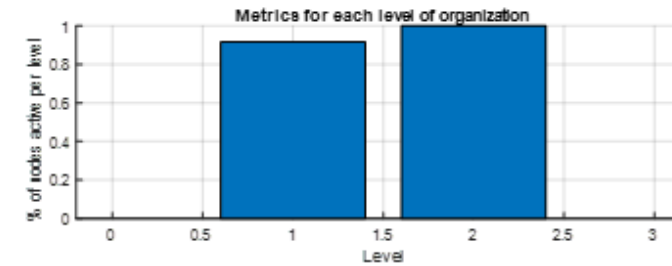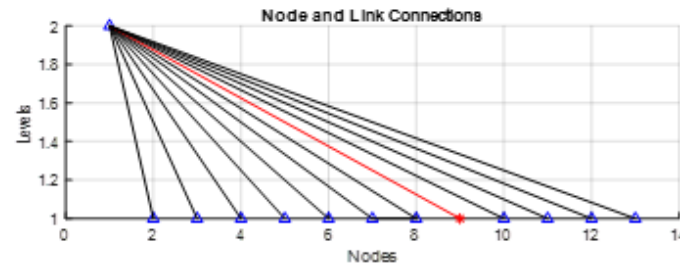
20%

Decision maker:
Not affected

EM Teams:
Some degradation
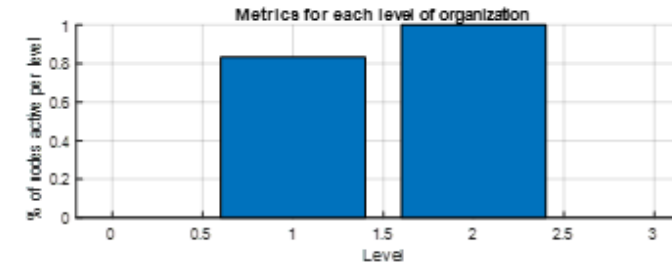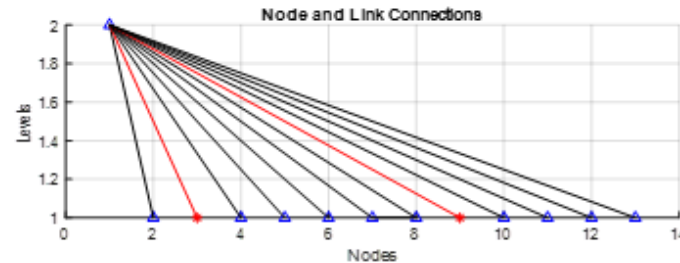
30%

Decision maker:
Not affected

EM Teams:
More degradation
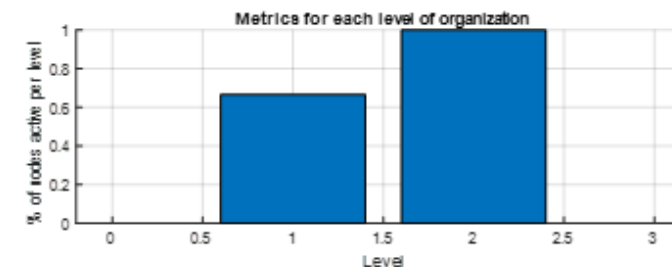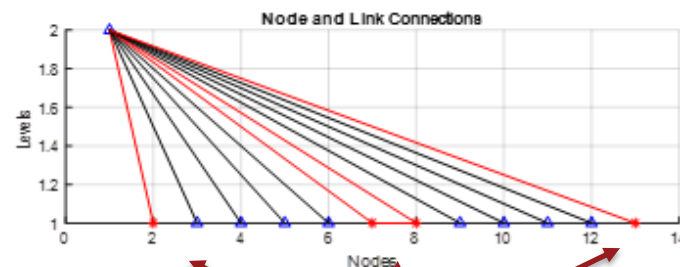
More nodes affected
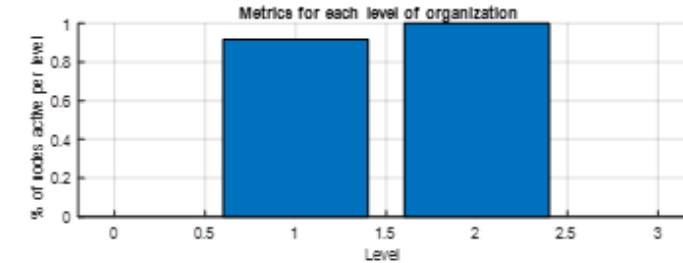
Situation 3 (Extended Response) Analysis
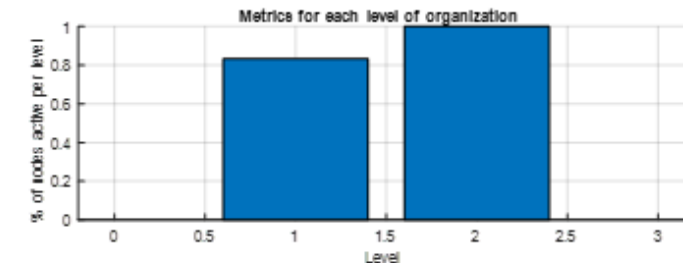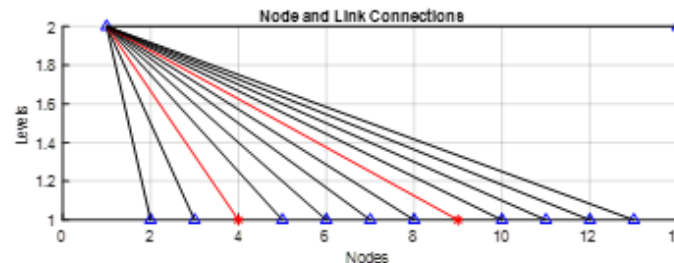
Decision maker node　　**External node**
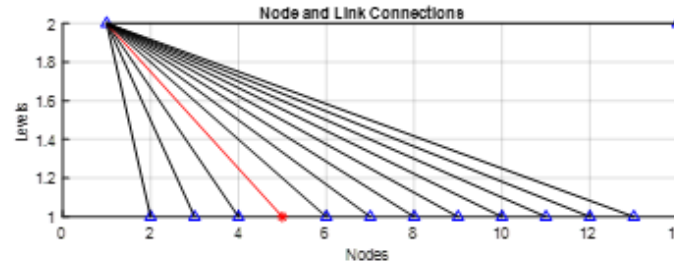
10%

Decision maker & external:
Not affected

EM Teams:
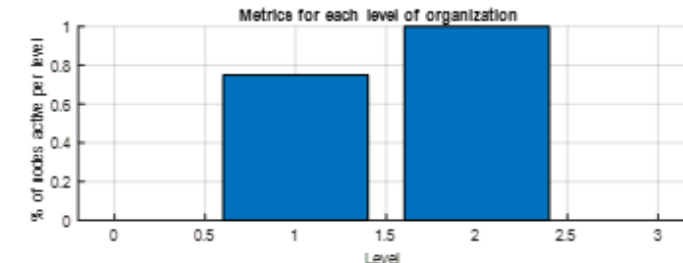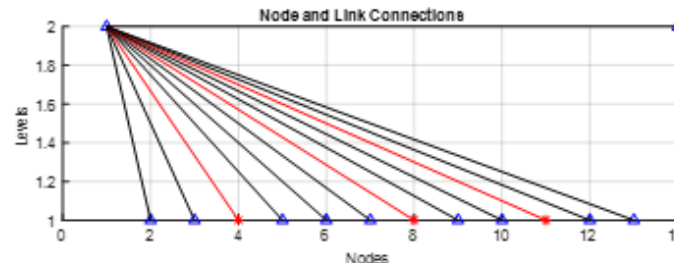Some degradation

20%

Decision maker & external:
Not affected

EM Teams:
Some degradation

30%

Decision maker & external:
Not affected

EM Teams:
More degradation

Situation 2 (Complex Problem) Analysis
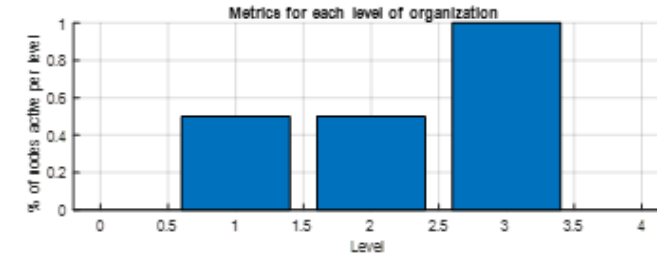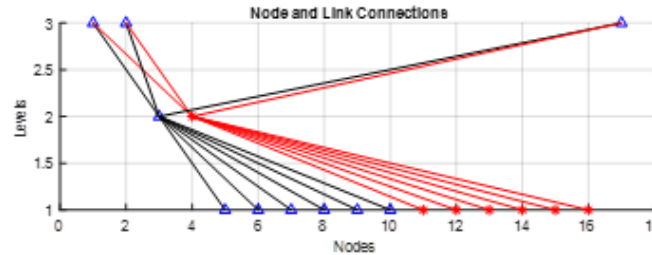
2 x Decision maker nodes

External node

10%

Top Decision maker & external:
Not affected
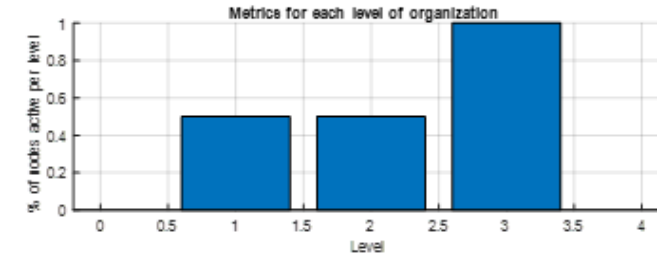
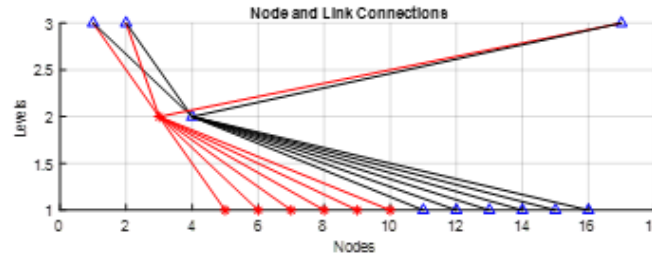Mid DM: affected

EM Teams:
More degradation

20%

Top Decision maker & external:
Not affected

Mid DM: affected

EM Teams:
More degradation

30%
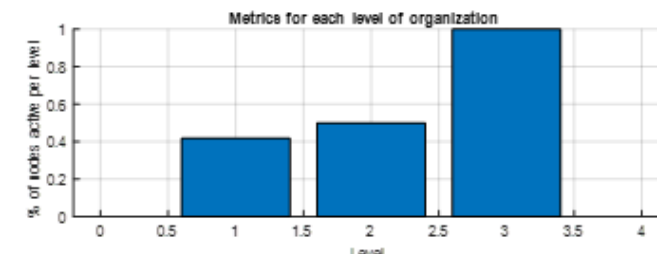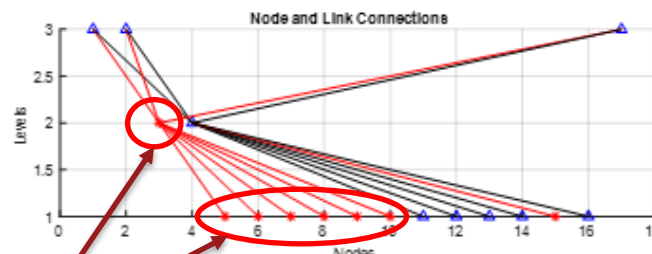
Top Decision maker & external:
Not affected

Mid DM: affected
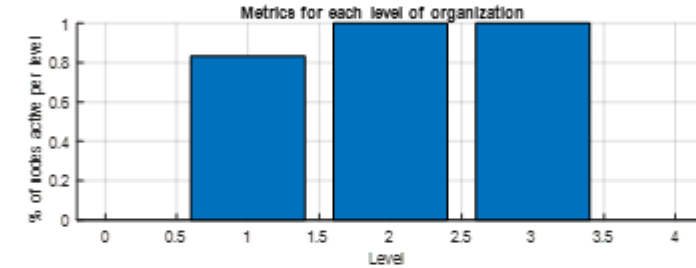
EM Teams:
More degradation

Cascading effect when the level 2 node is degraded and affects all subordinate level 1 nodes

Situation 1 (Large Complex Problem) Analysis

10%

Top Decision maker & external:
Not affected
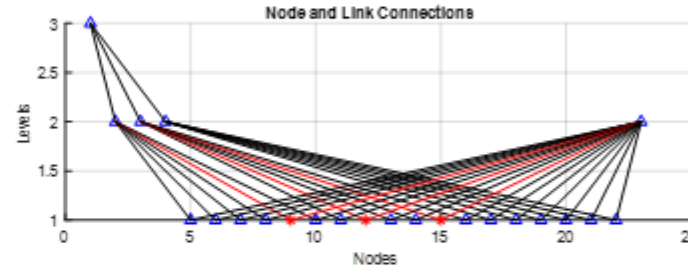
Mid DM:

EM Teams: **affected**
Some degradation

20%

Top Decision maker & external:
Not affected

Mid DM:

EM Teams: **affected**
More degradation

30%
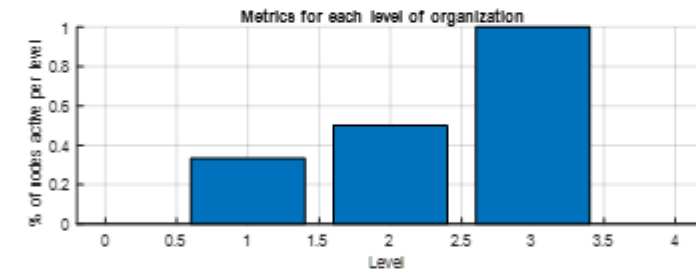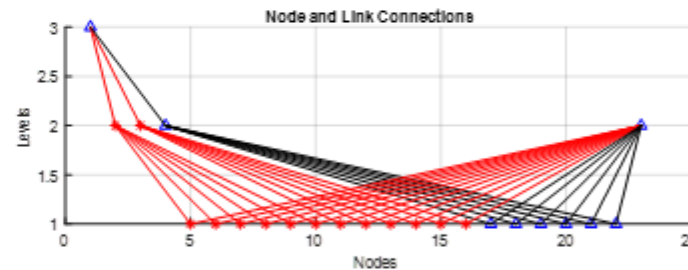
Top Decision maker & external:
Not affected

Mid DM:

EM Teams: **affected**
More degradation
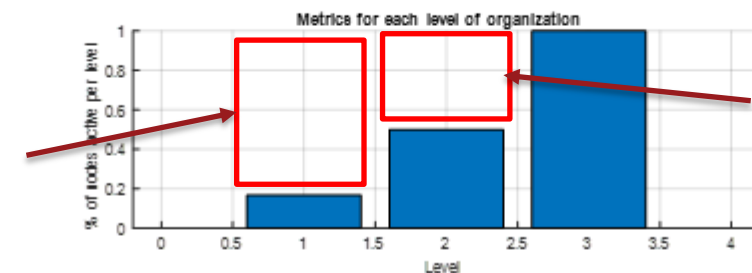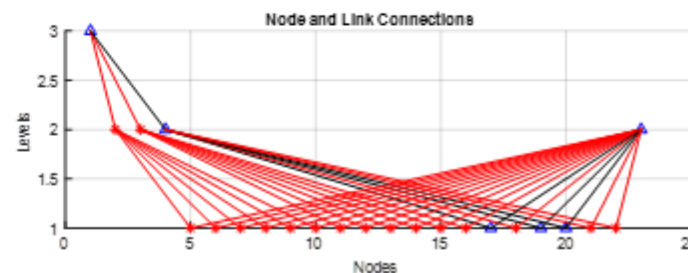
The impact is even greater when multiple level 2 nodes are degraded and affects the majority of subordinate level 1 nodes (e.g. now multiple firefighting teams may not have adequate situational awareness)

C2 Space for the Five Situations

- We find that for a bushfire experiment in our situations, better resilience for C2 can be achieved when the C2 provides:
  - More allocation of decision rights
  - Patterns of interaction among actors
  - Distribution of information
- We find that MBCD helped design and assess the abstract concept of C2 for resilience in the conceptual design phase.

Situation 1
Decentralised decision making
High patterns of interaction
High information dissemination

Situation 2
2-layer decision making
High patterns of interaction
information dissemination

Situation 3
2-layer decision making
Patterns of interaction
Some information sharing

Situations 4 & 5
Centralised decision making
Centralised interactions
Centralise information sharing

Distribution of information — Increasing dissemination

Patterns of interaction — Increasing interactions

Increasing allocation

Allocation of decision rights

In other words, better resilience outcomes are trending towards an "edge organization"

Summary

- We are able to leverage the MBCD schema to model the C2 structure and use it to perform analysis in terms of resilience

- We can evaluate how different levels of ICS are organized, and what they would have to deal with to combat bushfires

- In order to address greater complexity issues, may require additional toolsets and analysis to evaluate the efficacy of C2

Next Steps

- By analyzing the C2 aspect of a system, rather than the actual system performance, we were able to look at aspects for resilience improvement in terms of structure, organization, and information exchange
- Other areas of research could include:
  - A tabletop exercise concept to assist decision makers and planners in analyzing their strengths and areas for improvement, given a series of scenarios
  - Additional simulation efforts, such as agent-based modeling could evaluate the micro and macro level effects of communication and organization of multiple diverse teams
  - Examine the individual node and their interactions, leveraging social network analysis techniques, such as looking at the density, centrality, or distance of connections between nodes

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