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Resilience models for New Zealand's Alpine Skiers based on people's knowledge and experience: a mixed method and multi-step fuzzy cognitive mapping approach

Strickert, G.E. [1], **S. Samarasinghe** [1], **and T. Davies**[2]

[1] *Environmental Management Department & Center for Advanced Computational Solutions, Faculty of Environment, Society and Design Lincoln University, Canterbury, New Zealand*

[2] *Department of Geological Sciences, University of Canterbury, Christchurch, New Zealand*

Email: strickeg@lincoln.ac.nz

Abstract: Artificial Neural Networks (ANN) as a tool offers opportunities for modeling the inherent complexity and uncertainty associated with socio-environmental systems. This study draws on New Zealand ski fields (multiple locations) as socio- environmental systems while considering their perceived resilience to low probability but potential high consequences catastrophic natural events (specifically earthquakes). We gathered data at several ski fields using a mixed methodology including: geomorphic assessment, qualitative interviews, and an adaptation of Ozesmi and Ozesmi's (2003) multi-step fuzzy cognitive mapping (FCM) approach. The data gathered from FCM are qualitatively condensed, and aggregated to three different participant social groups. The social groups include ski fields users, ski industry workers, and ski field managers. Both quantitative and qualitative indices are used to analyze social cognitive maps to identify critical nodes for ANN simulations. The simulations experiment with auto-associative neural networks for developing adaptive preparation, response and recovery strategies. Moreover, simulations attempt to identify key priorities for preparation, response, and recovery for improving resilience to earthquakes in these complex and dynamic environments. The novel mixed methodology is presented as a means of linking physical and social sciences in high complexity, high uncertainty socio-environmental systems. Simulation results indicate that participants perceived that increases in Social Preparation Action, Social Preparation Resources, Social Response Action and Social Response Resources have a positive benefit in improving the resilience to earthquakes of ski fields' stakeholders.

Keywords: *Fuzzy Cognitive Maps (FCM), Artificial Neural Networks (ANN), Catastrophic Natural Events (CNE), Sustainable Hazard Mitigation (SHM), Earthquakes, Ski fields.*

1. INTRODUCTION

The Alpine areas of New Zealand boast some of the most spectacular landscapes in the country. The ski fields of New Zealand are significant contributors to the tourism industry contributing more than 100 million dollars annually directly to the New Zealand economy (Hotton, 2009). However, the recreational value of the ski industry and its economic value are highly vulnerable to catastrophic natural events. Catastrophic natural events (CNE) include severe weather, mass wasting, and especially earthquakes and their respective geomorphic consequences. Examples of resistant and resilient strategies for individual ski fields users are; people coming to the ski fields with: hazard awareness, sufficient food, water, and equipment (i.e. proper clothing). Ski field managers must develop and apply adaptive resilient policies. These policies must be practiced and be available in written emergency management plans that identify: self supported lifelines, robust communication, alternative power sources, safe zones for effective earthquake response, conditional evacuation plans, and post event reflection. The strategies for individual participants and management policies for all alpine ski areas are essential for securing this recreational resource for future generations. The policies and/ strategies must be developed by ski field stakeholders in a participatory manner to enable stakeholder support, understanding, and sufficient diversity of perspectives. Such stakeholder driven preparation, response, and recovery plans will ensure CNE do not become natural disasters where emergency managers and stakeholders are not able to cope adaptively with their consequences. Fuzzy cognitive maps (FCMs) is a form of mind mapping that enables researchers to gather data about complex and uncertain systems and analyse the data using Artificial Neural Networks (ANN). ANN "are a system of interconnected neurons organized into a network where each neuron processes data locally using the concepts of learning in the brain" (Samarasinghe, 2007). Using ANN we are able to simulate fuzzy cognitive maps (FCMs) of alpine skiers' perceptions. Moreover, we can extract inferences for learning how to improve resilience to CNE (particularly low-probability high-impact CNE, such as earthquakes) without first experiencing a natural disaster.

2. GOALS AND OBJECTIVES

The goal of this study is to identify and reconcile the views of ski fields managers, ski industry workers, and snow riders on how to prepare, respond, and recover adaptively and resiliently to earthquakes at ski fields in New Zealand. The preliminary analysis adapts Ozesmi and Ozesmi (2003) multi-step approach to FCM, but we modify their approach whereby participants are encouraged to define the most important variables for preparation, response, and recovery to earthquakes that can affect the ski fields. The information gathered will help to resolve four objectives which contribute to the overall goal of the project.

First, participants' *individual* maps undergo condensation and analysis using the established indicators of out-degree, in-degree, centrality, density, and through identification of transmitter, receiver, and ordinary variables (Ozesmi, 1999). Second, the detailed comparison of aggregated Social Group FCM (SGFCM) on condensed variables is demonstrated and explained. The SGFCM of Ski fields managers, ski industry workers, and snow riders are more useful for identifying policies than individual FCM because it enables a "lossy consensus" of participants' contribution while providing enough diversity of ideas from all three participant groups. Third, scenario simulations of SGFCM utilizing auto-associative neural networks are conducted. Conclusions are developed which enhance the adaptive capacity of all participant groups by identifying opportunities that improve resilience.

3. BACKGROUND LITERATURE

Ski fields are responsible for managing any "potential cause or source of harm" (Peters and Priestley, 2004). Therefore ski fields are responsible for managing two types of events (1) High probability low consequence events, and (2) Low probability high consequences events. For the first type, ski fields are exemplary communities of practice, (Wegner, 1998) that is, their current culture of safety functions very well with regards to reduction, readiness, response, and recovery to high probability low consequences events (i.e. physical injuries, severe weather and avalanches). For the second type, the management of low probability high consequence events such as earthquakes is not well established in the ski industry, as it is not significant in the horizons of ski field communities. (Pers Comm, Dave Masey, 2008).

On June 19th, 1994 the Porter Heights Ski Area tragically lost their grooming machine driver to a co-seismic (earthquake triggered) avalanche (Irwin, *MacQueen, and Owens*, 2002). The earthquake was centered near Lake Coleridge and measured 4.5 on the Richter scale. The combination of wind loading of heavy snow, and the ski fields' close proximity to the aftershock caused a size three avalanche to flip the groomer thereby crushing and killing its' driver (Irwin, *MacQueen, and Owens,* 2002). Questions arise about the potential result should a similar event occur when ski hills are operating at a regular capacity. Six earthquakes of 6.0 Mercalli scale (Mw) impacted Mammoth Mountain in 1980. Although no deaths were reported, building damage, rock fall, and resulting injuries were unexpected and serious (McJunkin and Bedrossian, 1980). McClung and Scharer (2006) outline earthquakes as potential triggers for avalanches, while noting their low probability. Earthquakes lead to cumulative impacts associated with melt-water and unstable soil. They note that the 1970 Huascar**a**n avalanche was seismically induced by a 7.9 Mw earthquake (Peru's most destructive), which caused a massive landslide (ice, rock, mud and water) of estimated 80 million cubic meters of debris. The Ancash earthquake and avalanche together killed 75,000 or more people. The landslide-avalanche itself buried over 20,000 people in Yungay, where only 400 people were estimated to have survived.

Perhaps the most seminal and comprehensive modern works on the subject of natural disasters is Mileti's (1999) work which re-emphasized the need for stakeholder participation in developing adaptive strategies for mitigation, preparation, response, and recovery plans at the community level, while highlighting a new paradigm in natural hazard management, namely managing natural hazards consistent with the sustainable development agenda; or 'sustainable hazards mitigation', a term he coined.

4. METHODOLOGY

4.1. Data Gathering

As a starting point several ski fields were visited to conduct geomorphic assessments of the possible consequences of earthquakes. In order to accurately assess these areas, they were visited during the summer to enable viewing the topography, geology, and infrastructure when it is not covered in snow. Between 2007 and 2008 a total of twenty-nine semi-structured qualitative interviews were conducted. The semi-structured interview was an attempt to illicit participants' perceptions and expert knowledge by tapping into their experiences with CNE in alpine ski areas. Our study adapted the Ozesmi and Ozesmi (2003) multi-step approach. During the interviews participants developed an FCM of the critical variables (important considerations) by drawing and circling the considerations they believe are important for preparation, response, and recovery to an earthquake that has a direct effect on the ski fields. Once they identified critical variables, their attention was shifted to a series of questions about their perceptions and experiences with CNE (i.e. natural disasters, severe weather, mass movements, and earthquakes) in alpine ski areas. The questions intensify their thinking about a scenario, which, as many interviewees reported, they had never considered. Once the questions were complete, the interviewer returned to the FCM asking if they wanted to add any more variables. Once satisfied with their selected variables, they were asked to assign important connections with strength values in the range of [-1, 1]. Of the twenty nine participants who completed FCMs, eight were completed by ski industry workers, ten were completed by snow riders, nine were completed by ski area managers, and two were completed by general respondents who were not associated with ski fields.

4.2. Fuzzy Cognitive Mapping and Auto-Associative Neural Networks

Fuzzy cognitive mapping is a form of mind mapping that enables researchers to gather data about complex and uncertain systems such as social-environmental systems. FCM also provides a view into the subjective world (i.e. people's knowledge systems) in a given context (Ozesmi, 1999). The maps represent the participant's perceived connections between important concepts with positive or negative influences in a specific context.

Fuzzy cognitive mapping is very useful in four types of problems where gaining insights or predicting system behaviour is not obvious or easy. These four types of problems are: 1) Prediction; which involves human behaviour and how human actions can unknowingly affect ecosystems, 2) Where detailed scientific data are lacking but local knowledge of people adapted to an ecosystem is available though less awareness and acceptance of knowledge systems is prevalent, 3) "Wicked" environmental problems…are complex, involve many parties, and have no easy solutions or right answers, 4) Issues in ecosystem management where public involvement is desired or even mandated by law." (Ozesmi and Ozesmi, 2003). Managing catastrophic natural events (i.e. earthquakes) in New Zealand's alpine ski areas is well suited to cognitive mapping as it exemplifies all four types of problems outlined above. The multi-step fuzzy cognitive mapping approach analyzes how people perceive a system, and compare and contrasts the perceptions of different people or groups of stakeholders.

Auto-associative neural networks are dynamic simulators that consist of neurons with feed-forward and feed-back connections, such that for a given input situation, the neurons activate each other processing information until the network reaches a steady state or chaotic attractor (Reinmann, 1998).

5. ANALYSIS

5.1. Map Condensation and Aggregation

The individual participant's fuzzy cognitive maps were condensed in a qualitatively subjective manner that has been justified by Ozesmi and Ozesmi (2003). The condensation enables aggregation of "similar" variables into high level categories/concepts for condensation of FCMs into SGFCM. In this study, 289 variables were condensed into 10 categories: Table-1 shows the categories and examples of critical variables (key considerations) for preparation, response and recovery to earthquakes as identified by participants.

Table-1 High level categories (condensed variables) and examples of critical considerations

High Level Category	**Examples of Critical Variables in Participants FCMs**
Lifelines	food and water, road access, communication, and energy
Negative (Adverse) Physical Effects	aftershocks, avalanches , rock fall, and building collapse
Physical Preparation	safe zones, rescue equipment
Physical Recovery	certified engineers' assessments and rebuilding infrastructure
Physical Response	chair-lift evacuation, and immediately assessing infrastructure
Social Recovery	reflecting, debriefing, and updating emergency procedures
Social Preparation Action (SPA)	hazards awareness courses, training, and buddy system
Social Preparation Resources (SPR)	communication tools, customer involvement, and Emergency Management Systems
Social Response Action (SRA)	effective communication, medical attention, and evacuation
Social Response Resources (SRR)	emergency (contacts, personnel, and procedures)

Once the upper level categories are identified, individual FCM can be aggregated into SGFCMs for each of the participant groups (ski industry workers, snow riders, and ski area managers, as well as an Total Social Group FCM (TSGFCM) for all participants in the study . The aggregations are completed by matrix addition of the individual FCM to create the SGFCMs and the TSGFCM. The SGFCM enable comparative analysis between stakeholders groups to indentify similarities and differences. The results of these analyses influence how simulations are conducted and whether the model is fit for optimization using Auto-associative networks.

5.2. Map Exploration/Preliminary Analysis

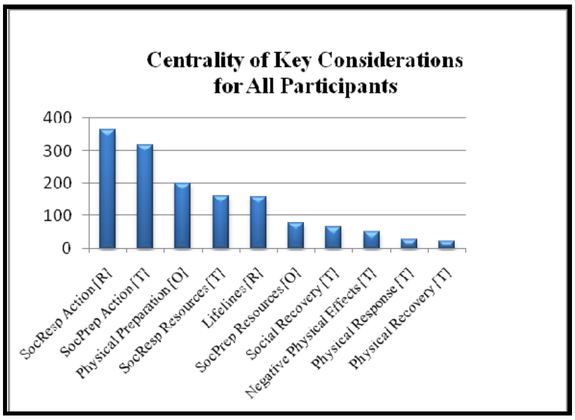
Conducting an exploratory analysis of the FCMs requires "finding transmitter variables (forcing functions, givens, heads), receiver variables (utility variables, ends, tails), ordinary variables, and immediate domains" (Bougon et al., 1997; Eden et al., 1992; Harary et al., 1965, as cited in Ozesmi, 1999). These variables are defined by their outdegree strength of connections going out (i.e. row sum of absolute values) and indegree strength of connections coming in (i.e column sum of absolute values). Transmitter variables have non-zero outdegree and zero indegree, whereas receiver variables have non-zero indegree and zero outdegree. Ordinary variables have both non-zero indegree and outdegree. The immediate domain (a.k.a total degree or centrality) is the summation of outdegree and indegree, and is an indication of the "importance" of a single variable in a cognitive map. Density (D) is a useful index of the entire map outlining the connectivity of a cognitive maps where $D = C/N^2$, where, C is the number of connections that exist, and N is the maximum number of connections possible (Hage and Harary, 1983, in Ozesmi 1999). Cognitive interpretation diagram (Appendix A) and an Auto-associative Neural Interpretation diagram (Appendix B) provide visual representation of variables types and key connections.

Table-2 Summary of data by respondents' social groups

	Ski Industry Workers		Snow Riders		Ski Area Managers		General Respondents	
Number of:	Avr.	STDV	Avr.	STDV	Avr.	STDV	Avr.	STDV
FCMs	8	Not Applicable	10	Not Applicable	9	Not Applicable	2	Not Applicable
Variables	9.75	±2.76	6.26	±2.39	8.11	±3.30	9.50	±3.38
Receiver	4.00	±1.93	4.30	±1.89	3.56	±1.67	3.00	±1.60
Transmitter	4.13	±2.36	4.80	±1.55	3.56	±2.88	4.00	±2.47
Ordinary	0.75	±1.04	0.50	±0.97	0.11	±0.33	1.50	±0.30
Connections	48.75	±45.95	50.80	±25.14	22.67	±12.63	20.50	±11.46
Density	0.005 66	±0.00458	0.0051 2	±0.02621	0.0139	±0.01070	0.0042	±0.0107

*Note: There were no significant differences between respondents' FCMs in both One-Tailed and Two-Tailed t-tests.

Figure-1 Centrality (*Immediate Domain*) of key considerations for all participants in TSGFCM.



One-tailed and Two-Tailed T-Tests indicated no significant differences between participant groups SGFCMs. Therefore, TSGFCM is used for conducting simulations. Figure-1 shows the centrality of key considerations (critical variables) for SGFCM of all participants, and outlines variables types as [R] receiver, [T] transmitter, and [O] ordinary variables. According to the TSGFCM, the most central variables in order of importance are Social Response Action, Social Preparation Action, Physical Preparation, Social Response Resources, Lifelines, Social Preparation Resources, Social Recovery, Adverse Physical Effects, Physical Response, and Physical Recovery. This enables prioritization of the variables to be clamped as a decision variable during auto-associative simulations.

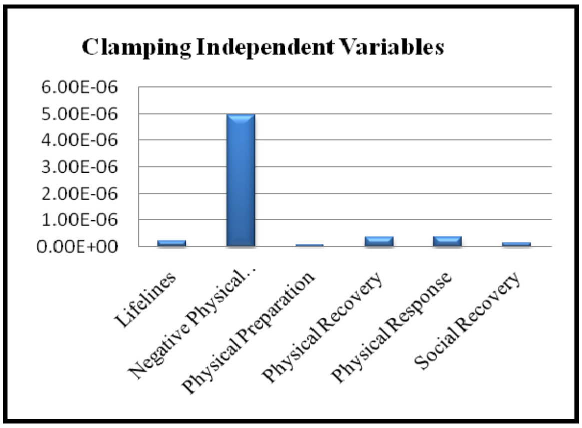
5.3. Scenario Simulations: Auto-associative ANN

In the auto association ANN, the TSGFCM variables were treated as neurons with logistic activation connections as weights. Auto-associative ANN simulations were run by multiplying adjacency matrices (A) by initial variables states (I^n) inputs set at 1. This computes the weighted input to the neurons. The output of this computation is then applied to a sigmoid function (the matrix containing connections strength between variables transforming variables between 0 - 1). This process continues through many iterations until a system reaches a steady state or chaotic attractor (Reinmann, 1998 as cited in Ozesmi, 1999). Auto-associative simulations enable experimentation with scenario strategies for increasing resilience to earthquakes. For example, simulations are run by clamping the independent variables (Social Preparation Action, Social Preparation Resources, Social Response Action, and Social Response Resources) at 1 through each simulation step; and then comparing the differences between their respective outputs to the steady state of the TSGFCM. Steady state is the corresponding outputs for variables as they are without clamping. Simulations are run by clamping only the independent variables because they are more realistic policy options than clamping the dependent variables.

Figure-2 demonstrates the slight positive changes (difference from steady state) to dependent variables (Lifelines, Negative Physical Effects, Physical Preparation, Physical Recovery, Physical Response, and Social Recovery). Clamping (i.e. setting the value at 1 at each iteration) the independent variables at a high level has a very small positive influence on the dependent variables, and a small but more noticeable positive influence on Negative Physical Effects. Based on the results of this simulation, the SGFCM of all stakeholders perceive that by clamping the independent variables at a high level (increasing Social Preparation Action, Social Preparation Resources, Social Response Action, and Social Response Resources) decreases the negative physical effects of an earthquake on the ski fields.

Other simulations found that clamping the four independent variables separately demonstrates that social preparation action, and social preparation resources have the highest positive influence on all of the dependent variables. Whereas, clamping social response action and social response resources has a less powerful positive influence on all of the dependent variables. The only notable exception is that social response action has a comparatively trivial positive influence on curtailing negative physical effects.

Figure-2 Change to Dependent Variables after clamping Independent variables at 1.



* Note: The changes are very small by virtue of the use of the sigmoid function during simulation; they are small but nevertheless important.

6. SUMMARY AND CONCLUSIONS

The auto-associative neural network method is a useful tool for simulating complex socio-environmental systems. The results of simulating the TSGFCM of all participants in this study was that by increasing and improving the following: SPA (hazards awareness courses, training, and buddy systems); SPR **(**communication tools, customer involvement, and trained medical officers); SRA (effective communication, medical attention, evacuation, and safety); SRR (emergency contacts, personnel, and procedures), there would be improvements in Physical Preparation (safe zone and rescue equipment); Lifelines (food and water, and energy); and Physical Response (chair-lift evacuation, and immediately assessing buildings and infrastructure). Moreover, Physical Recovery (certified engineers' assessments and rebuilding infrastructure) and Social Recovery (reflecting, debriefing, and updating emergency procedures) would also be improved. Finally, participants also perceived that combining the above strategies would curtail the Negative Physical Effects of earthquakes on ski fields. The information obtained from this study should be valuable for developing policies and strategies to help improve resilience to CNE for New Zealand's alpine ski field stakeholders as well as the livelihoods of the people living in ski field communities. The approach and results provide insights into sustainably building resilience to earthquakes for people living in and around mountainous landscapes.

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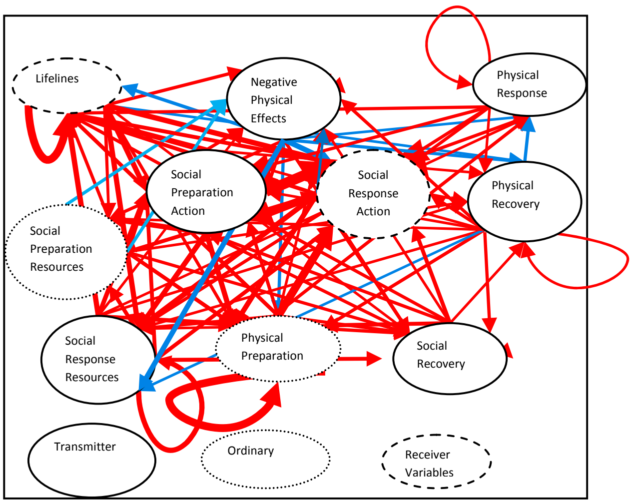
Appendix-A



Appendix-B