Resilience, Vulnerability, and Adaptive Capacity: Implications for System Performance

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ABSTRACT: As our infrastructure and organisations become ever more networked and interdependent there is a growing need to focus on managing overall system risk. In particular, there is a need to focus not only on the vulnerability of our systems to failure, but also on our ability to manage and minimise the impact of any failures. This raises some interesting concepts in terms of how we might design systems to be more resilient to change. For example, the traditional engineering approach had been to design systems that are less vulnerable to damage from hazard events. However system resilience can also be enhanced by increasing the adaptive capacity of the system, either through ensuring the system design includes enough redundancy to provide continuity of function, or through increasing the ability and speed of the system to evolve and adapt to new situations as they arise. This paper discusses the particular challenges for evaluating the resilience of organisations to major hazard events.

KEYWORDS: resilience, organisations, systems, vulnerability, recovery.

1 Introduction

Organisations manage, maintain and operate our infrastructure, create our economy and contribute to our society. The ability of organisations to continue to function in the face of unexpected events, such as major hazard events, will have a large influence on the length of time that essential services are unavailable, and on the duration of recovery for the community as a whole. There is a need therefore to be able to critically evaluate the consequences hazard events may have on organisations.

A significant challenge to achieving this goal however, is the complexity of organisations, and the ever changing context within which they operate. This paper explores how systems concepts might be used to help make sense of this complexity, and suggests a potential framework for evaluating the resilience of organisations.

The economic imperative to build businesses and organisations that are more resilient to hazards was clearly illustrated by the September 11th attacks, where business interruption losses far exceeded the sum of all property losses (Munich Re, 2001). An organisation's ability to respond effectively will depend, to a large degree, on their organisational structure, the management and operational systems they have in place, and the resilience of these. The economic implications of organisations being unprepared for high impact events are significant. Consequences go beyond the zone of physical damage, affecting businesses right along the supply chain. After the 1989 San Francisco Bay Earthquake it is estimated that 50% of small businesses directly affected were permanently disabled, with the resulting job losses significantly impacting the economy of the area (EPICC, 2003). Having more resilient organisations is a key component towards achieving more resilient communities because it is organisations that deliver essential services and provide employment for a large proportion of the community.

Knowing that organisations are an important component towards creating more resilient communities is one thing, effecting change to encourage organisations to increase their resilience is another. Particularly when the return period of the event is significantly longer than the planning horizon of the organisation, creating a compelling business case for investing in greater resilience can be difficult. Key requirements towards achieving this are:

- The development of simple yet effective methodologies that organisations can use to evaluate their resilience and strategies for organisations to improve their resilience.
- There is a need for common terminology to facilitate dialogue and debate within organisations about their resilience priorities, and to enable communication between organisations about common issues and interdependencies in their resilience strategies.
- Metrics are also needed for evaluating resilience. These metrics must be both meaningful to decision makers within organisations, and directly relevant to the overall goals and objectives of the organisation.

2 Taking a Systems View of Organisations

Organisations are highly complex and dynamic entities, where it can often be difficult to identify direct cause and effect relationships. Different parts and/or players in an organisation are interconnected by multiple feedback loops and complex interactions. This means it can be difficult to understand the impact a particular decision or action may have on the overall system. Systems analysis provides a useful framework for attempting to evaluate this type of complexity.

Even without going into detailed analysis and modelling of system dynamics, a great deal of insight can be gained by looking at a complex entity such as an organisation in terms of its systemic properties, such as:

- Articulation of the system purpose, and from that, defining the system boundary (i.e. what is inside or part of the system and what is not).
- Identification of the different components or elements that the system requires in order to achieve the system purpose.
- Examining the relationships between these different components and elements to understand how they work together to achieve the system purpose.
- Reviewing how the system interacts with its environment; its influence on the environment, and how the environment effects change within the system.

A simple representation such as that shown in Figure 1 can be used to pictorially represent these ideas. A framework like the Healthy Systems Criteria (Elms, 1998) can then be used for a high-level evaluation of the system quality.

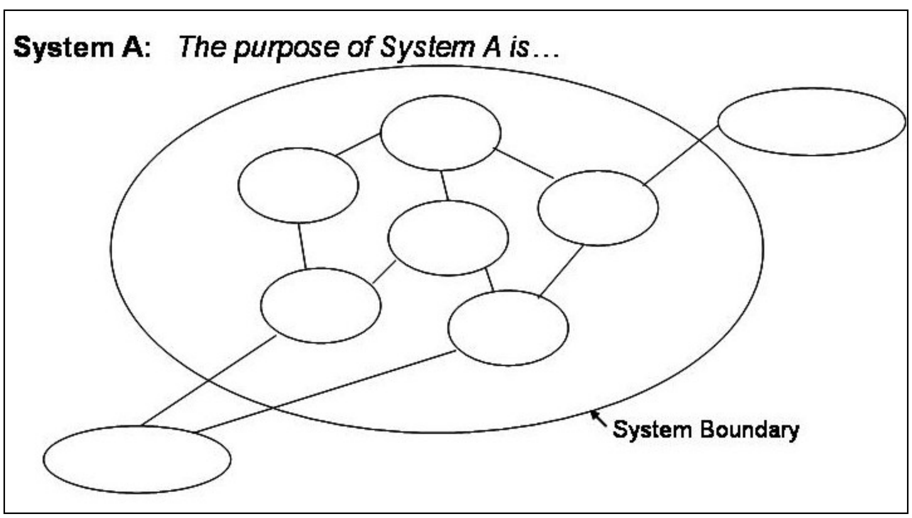

Figure 1: Simple Representation of a System

A key concept within systems analysis is the recognition that "the whole is greater than the sum of its parts". The emergent properties of a system cannot be understood by analysing the components of the system in isolation. For example, it is not possible to fully understand the way that a team of people work together by analysing the way that they work in isolation. By interacting with each other, each person will naturally modify their behaviour to respond to their colleague's ideas, mood, and actions. Similarly, the effectiveness of any organisation is a function of not only how effective each of its individual departments are, but also on how well these departments work together for the good of the organisation. Understanding the relationships between the different components is important in understanding the behaviour of the total system.

Once we have an understanding of how a system functions during 'business-as-usual' operations, a further challenge is to understand how the system will perform when it is placed under stress, either from internal or external pressures. This is a critical step towards being able to predict the secondary consequences of hazard events.

3 Terminology

In this section we explore some of the different terminologies used in the literature to describe system behaviour under stress, and how these relate to system resilience.

3.1 Vulnerability

Within the context of disasters, vulnerability is generally described as the human product of any physical exposure to a disaster that results in some degree of loss, combined with the human capacity to withstand, prepare for and recover from that same event. It describes the relative degree of 'risk, susceptibility, resistance and resilience' to a hazard event or disaster (McEntire, 2001).

Individual research disciplines tend to adopt definitions of vulnerability that explicitly suit their own needs. While the study of vulnerability began with the social sciences, the applications have reached far into economics, geophysical sciences, information systems, environmental science and politics, and include organisational management and policy decisions.

Vulnerability is inherently complex, and is not a static entity. There is a spatial-temporal element to vulnerability research in which different aspects of vulnerability become dominant at different times and in different places. For detailed case studies and surveys of vulnerability using qualitative and semi-qualitative methods, see Alesch and Holly, 1998; Alesch et al, 2001; Tierney, 1997; Webb et al, 2002; Luers et al, 2003; Stephen and Downing, 2001; Chang and Falit-Baiamonte, 2002.

Often, vulnerability is defined by one of its causal properties, for example poverty. When analysing vulnerability however, one must be aware that not everyone suffers the same way in response to the same event (Delor and Hubert, 2000). Some researchers contend vulnerability cannot, and perhaps should not, be reduced into simplistic term (Watts and Bolhe, 1993).

One of the most pressing challenges in modern vulnerability and disaster research may be to find ways of assessing the inherent vulnerability that exists in the daily life of the general population (Wisner and Luce, 1993; Delor and Hubert, 2000). Looking from a systems perspective, ways forward for evaluating vulnerability may include (after Delor and Hubert, 2000):

- Identifying the things that actually make individuals, communities or organisations work on a day to day basis,
- Assessing the inherent vulnerability of all these elements,
- Assessing how the interaction of these elements affects their vulnerability,
- Finding ways of enhancing their ability to cope with crisis situations.

3.2 Adaptive Capacity

Adaptive capacity is also a term that has emerged from several different disciplines. Luers et al (2003) introduce the concept of adaptive capacity into their vulnerability assessment of agricultural systems in Mexico. Adaptive capacity, the authors argue, is a significant factor in characterising vulnerability and may be defined as *'the extent to which a system can modify its circumstances to move to a less vulnerable condition'* (p 259).

The concept of adaptive capacity is also at the core of current business continuity strategies. Adaptive capacity is defined by Starr et al (2004) as the ability of an enterprise to alter its *'strategy, operations, management systems, governance structure and decision-support capabilities'* to withstand perturbations and disruptions.

Adaptive capacity reflects the ability of the system to respond to changes in its external environment, and to recover from damage to internal structures within the system that affect its ability to achieve its purpose.

A system can adapt to changes in various ways, including:

- *Application of existing available responses to address the problem.* This may include increased utilisation of existing resources and/or functionality. For example, where a business loses a major customer, its response may be to increase its sales effort to sell more products to its other existing customers.
- *Application of an existing response in a new context to address the problem*. For example, if a region suffers an economic downturn, an organisation may chose to develop new markets in other economies to offset its lost revenues. It has developed markets before, so has the knowledge and skills available to do this, but will be applying these skills in a new region where it does not have existing contacts.
- *Application of novel responses to address the problem*. For example, where an organisation loses a major customer that is very difficult to replace, the organisation may decide that the product is no longer economically viable, and invest in research and development to find alternative market propositions.

The response of a system to change can arise organically, reflecting the self-organising capacity of the system, or more mechanistically. Within organisations, these two spectrums can both be observed. For example, the crisis management structure of some organisations tends towards a more mechanistic command-and-control type structure, where the response of the system is directed and co-ordinated through formalised communication channels. By contrast, other organisations are more organic, exhibiting diffuse communication (utilising personal relationships as effective communication channels), decentralised decision making, and influence and power based on expert's knowledge rather than on formal authority (Knowles and Saxberg, 1988).

3.3 Resilience

The term resilience was first proposed in ecological research (Holling, 1973) to distinguish between;

a) a system (an ecosystem, society or organisation for example) that persists in a state of equilibrium (stability) and;

b) how dynamic systems behave when they are stressed and move from this equilibrium.

Resilience expands on vulnerability and may be viewed as the qualities that enable an individual, community or organisation to cope with, adapt to and recover from a disaster event (Buckle et al, 2000; Horne, 1997; Mallak, 1998; Pelling and Uitto, 2001; Riolli and Savicki, 2003).

A significant challenge with the terms 'resilience', 'vulnerability', and 'adaptive capacity', is that they are used in different ways by different research communities, and these meanings can vary from their common usage. In particular, the terms 'resilience' and 'vulnerability' are often used to mean similar concepts. Some, but not all, disciplines include the ability of a system to respond to change in their definition of vulnerability. We propose using the term 'resilience' to describe the overarching goal of a system to continue to function to the fullest possible extent in the face of stress to achieve its purpose, where resilience is a function of both the vulnerability of the system and its adaptive capacity.

In summary, the point at which a disaster occurs is when an individual, a community or an organisation is pushed from one state of relative stability or equilibrium into another. The ease with which the individual, community or organisation is pushed into this new state is a measure of their vulnerability, while the degree to which they are able to cope with that change is a measure of their adaptive capacity. The distinctions between vulnerability and adaptive capacity in relation to disaster events can be summarised by Figure 2.

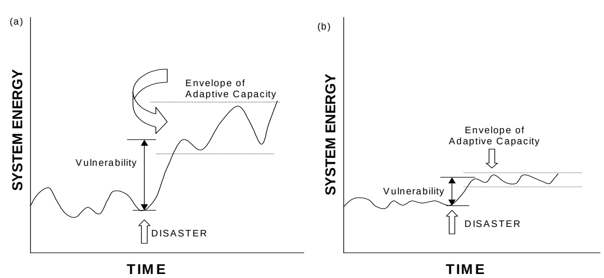

Figure 2. The relationship between vulnerability and adaptive capacity of a system in relation to a disaster event.

(a) *This system shows a high vulnerability as it may be easily pushed from one state into another. A large envelope of adaptive capacity shows that the system has to expend considerable amounts of energy to cope with changes following the disaster event. Often, the adaptive capacity, or resilience before the event may give some indication as to the likelihood of successful adaptation following the event.*

(b) *This system shows a relatively low vulnerability as it is not easily pushed from one state to another. The small envelope of adaptive capacity indicates a higher resilience to the disaster event. Note that this system also has a high level of adaptive capacity before the event.*

It is important to note that in the literature there are two types of resilience: engineering resilience and ecological resilience (Gunderson & Pritchard, 2002). Engineering resilience is the speed of return to the steady state following a perturbation, which implies a focus on efficiency of function. Ecological resilience is defined as the magnitude of disturbance that can be absorbed before the system restructures, which implies a focus on maintaining existence of function.

From an organisational perspective, it is interesting to question which type of resilience is aspired to. High engineering resilience implies maximising the efficiency of systems and processes to return and maintain the system at its desired state relatively easily and rapidly. Ecological resilience implies designing flexible systems and processes that continue to function in the face of large disturbances, even though this may not maximise efficiency. Increasing the ecological resilience of an organisation would effectively increase the magnitude of consequences the organisation could withstand before suffering irreparable damage.

4 Recovery –Recovery to what?

A key concept within system resilience is the ability of the system to respond and recover from an event. A question remains however; recover to what? In highly dynamic environments, such as the business world, an organisation is never a static entity. Some sectors will be more stable than others, but nevertheless, an organisation that remains exactly the same over time will eventually erode its potential to achieve its purpose. In an ever changing environment, a system must also change in response to that environment in order to retain its advantage.

This has interesting implications for an organisation hit by disaster. It implies that the organisation should not aim to recover and rebuild itself to be the same as it was before disaster struck, but should recover to a new equilibrium, where it will regain synergy with its external environment. Its' post-disaster condition may lead to a very different organisational structure than before the disaster event (Figure 3).

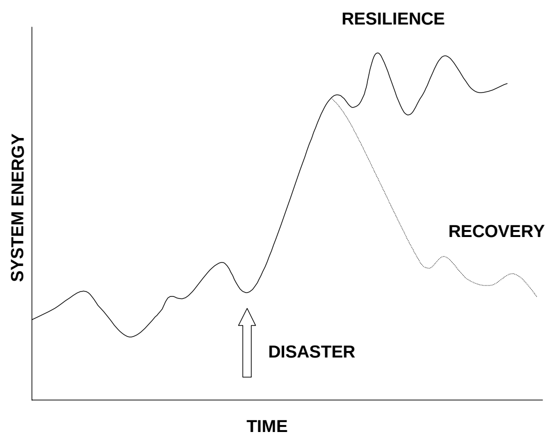

Figure 3: The relationship between organisational resilience and recovery.
When an organisation focuses on resilience, it is prepared to adapt to a new set of circumstances following a disturbance. When the focus is on recovery, the organisation strives to return to its pre-disaster condition. Often the aspects of the organisation that lead to its experience of the disaster are repeated, and there is no change in the adaptive capacity and possibly even an increased vulnerability.

This is synonymous with the concept of ecological resilience outlined previously and shows that organisations are complex self-organising systems with multiple equilibrium states. Organisations that focus solely on their post disaster recovery, rather than focus on becoming more resilient, will often try to return to their pre-disaster condition. However, recovery rarely addresses the causal problems leading to the disaster situation and may in-fact set up the next disaster (Tobin, 1999; Comfort et al, 1999).

This concept is also supported by disaster research, which indicates that that strongest indicator of a small to medium sized enterprise surviving a major hazard event is the extent to which the owner/operator recognises that the post disaster business environment is different, and adapts their strategies appropriately (Alesch et al, 2001).

Researchers wishing to understand and quantify the consequences of an event on dynamic systems face significant challenges. It is difficult to define when a system has fully recovered from an event, as there will never be a definite baseline from which to compare the observed performance of the system with what would have happened if the event had not taken place.

A way forward from this catch-22 may be to introduce sustainability concepts. Sustainable development implies activities that meets the needs of the present generation without compromising the ability of future generations to meet their needs (Bossel, 1999). For example, the use of fossil fuels in itself is not unsustainable, unless the rate of consumption of fossil fuels exceeds the rate at which suitable alternatives are developed.

Applying this concept to organisations, we propose that an organisation has recovered from an event, when it is no longer in a state of 'damage control' whereby it is necessary to focus solely on the immediate crisis, to the detriment of longer-term strategies and planning.

5 Metrics for Evaluating Resilience

As the management adage goes, "that which isn't measured isn't managed". Similarly, to see any real progress in getting organisations to invest to become more resilient, what is needed are metrics for measuring and benchmarking the resilience of actual organisations. This is by no means an easy task, particularly given the huge diversity of organisations. The other challenge is to ensure that these metrics are meaningful to those with influence within the organisation. In other words, these metrics must be easily translatable into a business case for investment.

One of the initial challenges is to frame the problem effectively. Organisations will be affected in a variety of ways by hazard events. Impacts will be at different scales for different parts of the system, and may be viewed as both positive and negative by different stakeholders.

Coming back to the system concepts discussed earlier, one of the first things defined for a system is its purpose. If we think of an organisation as a system, then a way forward may be to relate any measure of resilience directly to the ability of the organisation to achieve its stated purpose or objective. This objective could be taken from the organisation's mission statement. In general, these mission statements are multi-dimensional, reflecting the variety of stakeholder interests critical for the viability of the organisation. For example, an organisation's objectives might include:

- To deliver a sound financial return for shareholders,
- To provide a safe and rewarding environment for employees,
- To maintain a reputation for delivering a high quality product, on time and at reasonable value,
- To minimise environmental impacts, and to make a positive contribution to the local community.

Organisations will typically map their mission statement back to a series of key performance indicators (KPI's), which are tangible measures by which the organisation can track its performance against its stated objectives. The ease with which key performance indicators (KPIs) can be moved away from their desired levels will be a function of the system vulnerability. The time it takes for the system KPIs to recover will be a function of the adaptive capacity of the system. The overall resilience of the system will be a function of the area under the curve, which is the total impact on KPIs over the response and recovery period (Figure 4).

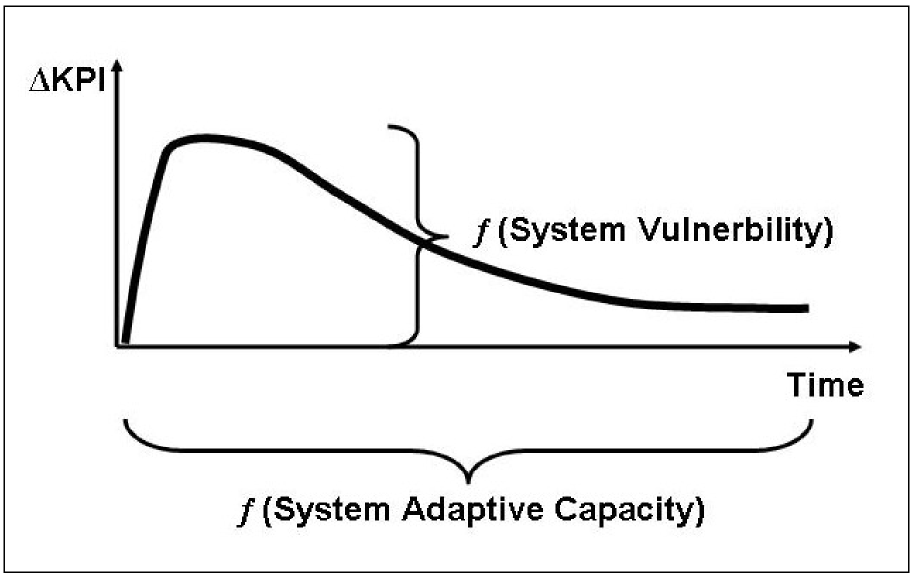

Figure 4: Severity and duration of impact on KPIs as a measure of system resilience, where resilience is a function of the area under the curve.

6 Relationship between Resilience and Risk Management

Evaluating and improving system resilience is an important partner to traditional risk management techniques. Risk management typically focuses on the probability and consequences of particular events occurring. One of the major challenges in risk management is how to deal with ontological uncertainties. Ontological uncertainties are essentially the "unknown unknowns"; the events that have not been thought of, and therefore are not assessed or managed. By approaching the problem from a different angle, resilience management provides one strategy for dealing with these events. Resilience management shifts the focus from "*what could make the lights go out*?" to "*it doesn't matter what makes the lights go out, how are we going to deal with it if they do*?".

Taking a systemic view of organisations can also offer a different perspective on managing overall system risk. Traditional risk prioritisation techniques assume independence of risks, but in a global world where things are becoming increasingly interdependent, this assumption is questionable. Examples such as the Asian economic crisis and power blackouts in the US illustrate the vulnerability of many of our systems to cascade failure. The reasons for cascade failures such as these, lies not in the vulnerability of individual parts of the system, but in the relationships between the different parts of the system and the topography of these relationships. Recent research into the influence of network topology on the robustness and vulnerability of systems to failure (Barabási, 2002) has important insights for risk managers. Barabási describes two generic types of network: random networks and scale free networks (Figure 5).

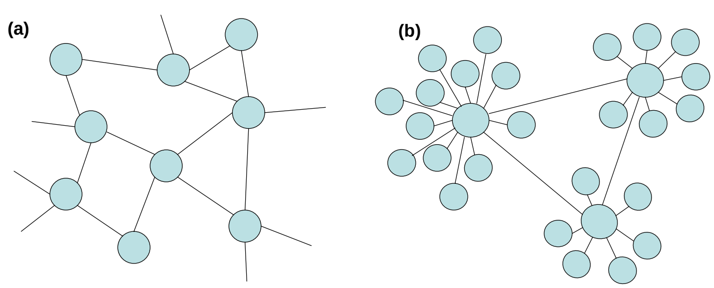

Figure 5: Illustration of a random and scale free network.

- *(a) A random network is one where the nodes have a relatively even distribution of links to each other. An example of a random network would be a road network, where most cities have a similar number (within an order of magnitude) of highways feeding into them.*
- *(b) A scale-free network is characterised by 'hubs', where a small number of nodes attract the majority of links. An example of a scale-free network is the internet, where millions of web sites have links to popular sites such*

as www.google.com or www.cnn.com, in contrast with the majority of websites which may only have a few links pointing to them.

For example, let us look at the two systems in Figure 5 transportation systems, where the purpose of these systems is to allow travellers to get from any location within the system to another. Taking this analogy, the system pictured on the left (Figure 5a) most closely represents a road network, where most of the different components in the system (towns) have a similar number of connections (roads in and out of the town). The diagram on the right (Figure 5b), could be described as a representation of flight connections, where smaller population centres feed into 'hub' airports. It is still possible to pass from any part of the network to another, but most journeys will pass through one or more hub airports.

These simple examples provide an insight as to how different types of system perform under stress. Within a random network, the failure of any one pathway between two nodes does not break the connection between those two links, as there are alternative routes via other nodes. In Figure 5a, if the road between an imaginary Town A and Town B were closed, then in most cases it is still possible to get there detouring via Town C. The network is initially relatively insensitive to random link or node failures until a critical threshold is reached. Beyond that critical threshold, the loss of any more links or nodes abruptly breaks the network into unconnected islands. This behaviour has interesting implications when trying to estimate the impact of future failures based on past experience. For example an ecosystem may have shown surprising resilience to past pollution spills, but the risk from future pollution spills may be much higher as the environment reaches a threshold of the amount of pollution it can absorb before collapse.

A scale-free network on the other hand is almost invulnerable to random-failures. Experiments using maps of the internet showed that you can remove as many as 80% of all nodes, and the remaining 20% still hang together in a tightly interlinked cluster (Barabási, 2002). The topology of a scale-free network however is also the source of its key vulnerability; to targeted attack. It only takes the simultaneous removal of a few critical hubs to disable the network. This property has also been observed in natural systems. Although the environment is generally resilient to random species extinctions, it is vulnerable to the removal of highly connected 'keystone species' from the food chain (Solé & Montoya, 2000).

These network properties highlight a catch-22, where designing systems to be less vulnerable to one type of failure (such as random high probability, low consequence events), we may create other vulnerabilities which make the system more vulnerable to catastrophic failure. For example, the use of integrated IT and communications systems enables the rapid and effective sharing of information throughout an organisation, but also creates the potential to simultaneously reduce the effectiveness of all parts of the organisation should it fail. Gaining a better understanding of these systemic vulnerabilities will lead the way to being able to manage these weaknesses and allows for more effective prioritisation of risk management investment.

By thinking more systemically about risks it may be possible to identify 'keystone' risk drivers to help prioritise risk management investment. 'Keystone' risk drivers are characteristics that exert influence on a number of different risks. Examples may be a certain group or function within an organisation, the viability of a certain species in the food chain, buy-in from a key stakeholder group during consultation, or a critical source of uncertainties.

Riolli and Savicki (2003) also suggest using a systems analysis approach evaluate organisational resilience. They propose that such an analysis will not only map resilience within the enterprise, but they identify the importance of '*influential superordinate-systems of which the organisation is only a part.*'

7 Conclusions

Organisations deal with uncertainties and unexpected events all the time. Some organisations, such as the emergency services are designed to manage them as part of normal operations. For a majority of others it is just part of normal business, where uncertainty presents both opportunities and risks. There is an operating envelope, within which certain scale events are part of normal business. Once an event moves beyond this scale, there is greater uncertainty about the organisations ability to respond, and the scale of potential impacts.

During and after a major disaster is a time when communities are least capable of absorbing service disruptions – hospitals, emergency services and response and recovery teams rely on water, power, communications and access to minimise risks to life and property. In New Zealand, this criticality is reflected in Civil Defence and Emergency Management legislation (CDEM Act, 2002), which places a statutory requirement on all lifeline service providers (such as water, electricity, communications, road access etc) to be able to function to the fullest possible extent during and after an emergency, and to have plans for such continuity that can be reviewed by the Director of Civil Defence on request. There is also a case for non-lifeline organisations to become more resilient to hazard events, as they also play a key role in the fabric of a community. Encouraging organisations to become more resilient however is difficult in the private sector, where planning for greater resilience is not a concept that can be regulated, but requires individual business owner and operators to recognise the need for greater resilience, be aware of strategies available for increasing resilience, and be prepared to invest to achieve this resilience. In essence, we need to develop and promote a persuasive business case for investing in more resilient organisations.

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