THE CONCEPT OF RESILIENCE IN COMMUNITY AND ENGINEERED SYSTEMS - A CROSS SECTORAL FEEDING OF IDEAS

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ABSTRACT

This paper outlines some recent work in organising the metaphor of "resilience" in application to engineered systems. This work provides an approach to the identification of threat types and magnitudes and the acceptable or desired outcomes to instances of the threats which can be used for specification of engineered system. The paper then explores the usage of the word family "resilience" in *The Australian Journal of Emergency Management*, a sector journal published by the Australian government. It is found that "resilience" is used as a metaphor, which is often described, in various ways, but not tightly defined. It is concluded that the emergency management sector would benefit from exploring the broadening and application of the engineering concepts to the less crisp issues related to the impact of threats on distributed community systems, so that appropriate disaster resilience development responses are made.

Keywords: Resilience; Emergency management; Engineered systems

INTRODUCTION

The idea of resilience is one which has grown in recent years in both engineering and community sectors. Is the recognition that all systems may be subjected to unfortunate events which will cause some kind of disruption or damage so that the system is no longer able to perform in the manner which was able to perform prior to the disruptive event the effect of the disruption is, immediately that the system cannot function as it had prior to the disruptive event and that some work is required in order to restore the system to a state in which it is capable of providing the functionality that it had prior to the disruption. The idea of resilience concerns the ability of systems, with appropriate inputs of work and tangible resources, to be restored in a reasonable time to an appropriate condition following a disruptive event.

Disruptive events which may impact systems can come from a variety of sources. The sources may be one of the following:

- weather related events, such as storms, floods or drought;
- natural disasters, such as earthquakes, volcanic eruptions, landslides, fires or tsunamis;
- human activity of a malicious kind, such as arson, criminal or terrorist activity;

- human activity of a nonmalicious kind, such as accidents caused by negligence, errors of judgement, miss recognition of the true situation or misunderstanding between people;
- failure of physical assets, such as equipment failure preventing service, damage caused to assets or by any other disruptive event and these failures could be caused by either design vulnerabilities of the assets to the particular events may encounter or by inadequate maintenance leading to vulnerabilities being developed by systems.

The summarising description of possible causes of disruption in the points above is merely a summary, and complex relationships between possibilities do exist. For example, the manifestation of a particular kind of disruptive event, such as a fire, could be caused by any of a variety of factors, including a storm, a malicious act by a person or an accident. Whilst the physical damage caused by the fire may be the same regardless of cause of the fire the reaction of the people who are victims of the fire is likely to be very different depending on the cause of the fire. Further, the opportunity of the victims to receive restorative assistance through methods such as insurance or broader-based community assistance, whether government or private supported, may be significantly impacted by the cause of the problem. The response of the people will reflect both the physical impact of the events upon them and the psychological impact associated with the nature of the cause and the extent to which individuals feel that they are sharing their experience with a broader community. In addition, the impact of a disruptive event depends in part on availability of assistance for victims, and so therefore will depend to some extent on the magnitude of the disruptive event compared with the resource base from which assistance could be drawn.

DEFINITIONS OF RESILIENCE

The common English definition of “resilience” is “the act of rebounding or springing back” (*Concise* 1976). This definition relates to materials which return to their original shape after deformation. This definition conveys a rhetorical sense that a system which is resilient is able to return to something reasonably approximating its original state. However it gives us no indication of any method by which that restoration could occur or any basis for measuring or otherwise judging the success of the restorative activity.

The inadequacy of the common English concept of resilience for use in any technical application, whether in relation to engineered systems or communities, is clear to all practitioners in both engineering and community support roles. The inadequacy of the common English usage of "resilience" is that the common usage does not enable the clear communication of what kind of outcome would be considered reasonable in the context of the particular system of interest and the particular threats being considered. The specificity of the idea of resilience to both the threats encountered and the results that would be considered acceptable is a necessary consequence of the great range of possible disruptive events, each of which would impact on the system in a different way based on the nature of the threat, the magnitude of the threat and the details of the system upon which it is impacting.

Concept of Resilience

In ecosystem scholarship resilience has been defined as: “the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes” (Resilience Alliance 2010). This definition is predicated on a view that systems can occupy any of a number of metastable states, with the possibility that the system can be transitioned from one to another as a result of certain input events. The idea of resilience of the system is that it is capable of returning to its original metastable state after being affected by some threat. Should the threat exceed the resilience capacity of the system the outcome would be that the system ends up in a new metastable state and cannot be restored to the original state.

Engineered systems are created through the process of design, in which the designers commence with a need for a solution to some experienced in adequacy of the current capabilities of engineered systems. The process of design leads to the creation of a system which has a designed configuration of elements of both designed and preconfigured kinds. That is, the designed system includes technological, natural and human elements, all of which are arranged, by design, in order to provide a solution to the need for which they have been developed. The technical of the elements of the system are designed to have properties which enable desirable characteristics to be achieved, and enable prediction and management of their response to various kinds of import, including a variety of threats. The natural and human elements of the system are not so controllable by the designer. The result is that the anticipation of the impact of threats on engineered systems is a complex and demanding task which can only provide information about Rangers of potential outcomes and cannot provide a deterministic description of the outcome that would be experienced in any particular case. In relation to the resilience of engineered systems the International Council on Systems Engineering (INCOSE) Resilient Systems Working Group has, similarly to other definitions of resilience associated with engineered systems, defined resilience as “the capability of a system with specific characteristics before, during and after a disruption to absorb the disruption, recover to an acceptable level of performance, and sustain that level for an acceptable period of time” (INCOSE 2010).

This definition introduces the notions of a timeline of response to a threat and the recovery of an acceptable level of performance. This definition certainly permits a system that is classified as resilient to suffer significant impairment, such that it is not suitable for its original purpose.

In the broader field of civil infrastructures, which refers to the assets developed by the society to support the community lifestyle The Infrastructure Security Partnership (TISP) has defined disaster resilience as “the capability to prevent, protect against or mitigate any significant threat or event, including terrorist attacks, and to expeditiously respond, recover and reconstitute critical assets, operations and services with minimum damage to public health and safety, the economy, and national security” (TISP 2010). This definition emphasises the ability of the system to achieve helpful recovery within a reasonable time and the idea of minimising deleterious consequential impacts of the threat and system response.

Again, from an engineering background, Haimes defines resilience as "the ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite costs and risks" (Haimes 2009). This definition includes the same primary elements contained in the INCOSE definition above, and clearly highlights that the amount of degradation of the engineered system that is considered acceptable is a matter of specification.

All of the definitions presented above are challenged by the fact that their authors are attempting to encapsulate the concept of resilience in a single sentence. In order for a single sentence to be passed with a reasonable level of complexity so that it is understood by most people it is necessary to summarize salient features of a complex concepts such as resilience rather than to completely identify and describe them. The effect of this fact of communication is that single sentence type definitions of resilience provide an attractive rhetorical expression of the idea but do not frame the idea of resilience in a manner which enables judgments such as what outcomes, or intermediate responses, would be considered acceptable in relation to a system suffering from a certain kind of threat.

What is needed to specify the resilience characteristics required of an engineered system is to identify a set of possible threat types and magnitudes and the acceptable outcome, see Table 1. The system design team must identify a range of relevant threat types, where the types depend on the nature of the system. For example, a large-scale infrastructure system would include threat types related to various types of natural disaster, accidental and deliberate human activity. For each of the threat types various magnitudes of threat could be identified. In order to make the specification problem tractable it is necessary to aggregate subtle variations of threat type into groups and to aggregate magnitudes for each threat into meaningful categories which would distinguish different kinds of response desired from the system.

Table 1. Specification of the system responses to various types and magnitude of threat.

Threat	**Magnitude$_1$**	**Magnitude$_2$**	**…**	**Magnitude$_m$**
Type$_1$	Response$_{11}$	Response$_{12}$		Response$_{1m}$
Type$_2$	Response$_{21}$	Response$_{22}$		Response$_{2m}$
…				
Type$_n$	Response$_{n1}$	Response$_{n1}$		Response$_{nm}$

For each magnitude of each threat it may be appropriate to specify a different response. For example, for small magnitude threats it may be appropriate to expect that the system would survive intact, with, perhaps only, some minor tempi disruption to supply service.

In contrast for a large magnitude threat it may be considered appropriate to allow that the system will experience a substantial failure, or even be destroyed. The judgment of appropriate responses of the system depends on case specific issues including the cost of preventive design work and the impact of any actual failure.

In table 1 the cells containing the responses are matrix in which a description of the response desired from the system to stated. The responses used in the specification can be guided by a set of resilience classes identified in other work of this author, working with colleagues.(Jackson, Ferris, and Cook submitted). The resilience classes for engineered systems are presented in table 2. The system outcomes described in these classes range from the relatively minor inconvenience of avoiding a threat or suffering an immediate impact within the design specification of the system, in class 1, through various stages of increasing severity and inconvenience through to total loss of the system, in different circumstances, in classes 3b and 4. The descriptions of the classes are reasonably broad, to enable inclusiveness of all anticipated possibilities in a reasonable number of categories, seven, but a sufficiently detailed to assist the process of specification of a particular instantiation of the class description which is relevant to the situation of the particular system under development.

Table 2. Resilience classes for engineered systems (Jackson, Ferris, and Cook submitted).

Resilience class	Description of resilience class
1a	The ability of a system to retain, or recover to, full service delivery following an encounter with a threat by performing evasive action.
1b	The ability of a system to retain, or recover to, full service delivery following an encounter with a threat as a result of absorbing or resisting the threat.
2a	The ability of a system that has suffered partial impairment following a threat encounter to be restored to full service delivery through repair work that entails system shut down.
2b	The ability of a system that has suffered partial impairment following a threat encounter to be restored to full service delivery through repair work that can be undertaken while the system is providing partial service delivery.
3a	The ability of a system to perform with partial loss of delivered service level for a reasonable time following a threat encounter and subsequently provides an alternative level of service provision followed by later restoration of full service.
3b	The ability of a system to perform with partial loss of delivered service level for a reasonable time following a threat encounter and subsequently provides an alternative level of service provision followed by later retirement of the system.
4	The ability of a system to perform an orderly shut-down following a threat encounter that has resulted in damage sufficiently severe as to provide no prospect of repair and restoration to service.

The strength of describing the resilience of the system in terms of the classes and subclasses described in table 2 is that this provides a conveniently small arrangement of categories which describe the intended outcomes in a generic manner to enable specific

specification of a particular system and to communicate with stakeholders what the system is designed to do under particular threat scenario conditions.

"RESILIENCE" IN *AUSTRALIAN JOURNAL OF EMERGENCY MANAGEMENT*

The *Australian Journal of Emergency Management* (*AJEM*) is published by the Attorney general's Department of the Australian government. As such it is designed as a multi-purpose publication which contains refereed research, various official statements, and news reports related to the emergency management field that are of archival relevance. Much of the subject matter is directly related to Australia, so most articles of all types address an Australian originated issue, although there are some articles, usually by international authors, which address issues originating elsewhere. In most cases of articles addressing international issues it would appear that the editors judge the article to have some instructive value to the Australian emergency management community. The refereed research is usually reported in a manner which is instructive to practitioners, and definitely in language which is easily read by people with no specific education in emergency management.

Method used in the study

All items published in *AJEM* between volume 10, number 1, Autumn 1995 and volume 27, number 2, June 2012, were word searched for the appearance of any of the words in the "resilient" group by using electronic search for the character string "resilien". The uses of words were identified and classified in order to provide insight into the understandings of the concept of "resilience" evidenced by the authors. The understandings of the authors in context were sought in the word study, without presupposition that there was an overarching single definition of resilience which they were all using. It was important to this study to allow authors to speak with their own voices and to have different definitions of resilience, which were what was sought through the study, rather than to try to impose a common definition, since the purpose was to explore the variety of meanings used.

The usages of "resilience" include a variety of types:

- A meaningful word in a context where the author is building meaning using the meaning of "resilience" as a contributing element.
- A name of a concept in which the word "resilience" is used as part of naming something with a commonly accepted compound word name.
- A proper name of some entity.
- Incidental uses including in the name of entities with which an author is affiliated, in the bibliographic details of sources referenced, in book reviews which do no expand concepts, and as part of notices and news item briefs.

Complex uses of "resilience"

Cottrell provides a developed discussion of factors relating to resilience, including the idea of vulnerability and the community dimension of resilience (Cottrell 2011). This discussion evidences the complexity of the notion of resilience and the means to achieve it and to identify its presence or absence. The difficulty with understanding and grasping the idea of "resilience" is that it is, according to Rogers, a metaphor, and therefore not intended as a word providing direct communication (Rogers 2011). The problem with frequent use of a word which is itself a metaphor is that in its metaphoric character it connotes many things to many people, and in these case, sounds like an unspecified desirable good and is therefore likely to become a means of miscommunication. Koob discusses the need for a glossary which would include "resilience" as a tool to provide unified definitions of terms across the emergency management sector, indicating the absence of a clear definition (Koob 1997-98).

Resilience is increased by loss minimisation actions during a disaster, accelerating return to normal life, which indicates that the idea of resilience concerns the capacity to re-establish normal life following an event (Finnis et al. 2004).

Idea of vulnerability and resilience

The two ideas of vulnerability and resilience are used as a hendyadic antonymous pair, sometimes arranged slightly differently. The idea conveyed is that vulnerability, that is the susceptibility to bad things happening because of some weakness or failing, is an antonym of resilience, which in some way refers to the ability to prevent the initial bad event occurring or to enable recovery from its effects, although the connection with vulnerability places the emphasis on the prevention rather than the recovery (Buckle 1998-99; Dovers and Norton 1999; Buckle, Mars, and Smale 2000; King and MacGregor 2000; "A strategic research agenda for emergency management" 2001; "Announcement Resilience and vulnerability assessment" 2001; Buckle and Hill 1995; Manock 1997; Coghlan 1998; Handmer and Dovers 2008; Buckle 2002; King 2002; Buckle, Marsh, and Smale 2003; Morrisey and Reser 2003; Handmer 2003; Dovers 2004; McDougall 2003; Buckle 1995).

Idea of community resilience

A common usage in *AJEM* is "community resilience". This concept conveys that whatever it is that resilience refers to is something which comes into existence in the context of a community and therefore involves the relationships of the people providing mutual assistance. This concept is conveyed by (Lahey 2011b; Nicholls 2012; Taylor et al. 2012; "Standing Council on Police and Emergency Management communique Auckland, 11 November 2011" 2012; Biggs 2012; Carter 2012; Eburn and Dovers 2012; "Profile: Dr Margot McCarthy Australia's new National Security Adviser" 2012; Johnston et al. 2011; Thomas et al. 2011; Frandsen, Paton, and Sakariassen 2011; Webber and Jones 2011; Sturzenegger and Hayes 2011; Lapsley 2011; "AEMI Master class report facilitating community-led recovery" 2011; Crawley 2011; Lahey 2011a; Childs, Carlisle, and Hastings 2001; Rodrigue 2001; Pearse, Johnston, and Becker 2001;

Wajs-Chaczko 2008; Tolhurst, Shields, and Chong 2008; Crompton and McAneney 2008; Sullivan 2008; Koob 1996; Wapling 1996; Tarrant 1997-98; Young 1998; Indian 2007; Lewis 2008; Proudley 2008; Goodman and Gawen 2008; Walia 2008; Fallahi 2008; Eburn 2008; Beckenham and Nicholls 2004; Coles and Buckle 2004; King and Gurtner 2005; "In profile: Bruce Esplin" 2005; Floyd 2005; Ruddock 2006; Childs 2006; Lewis 2006; Saunders et al. 2007; Maguire and Hagan 2007; Bushnell and Cottrell 2007; Meo and Ziebro 2002; Handmer 2002; McLachlan 2003; Gabriel 2003; Hocke and O'Brien 2003; Prestipino 2004; Britton 2002; Dufty 2012).

Uses of "resilience" in papers – "resilience from" or "resilient to"

A common construct in the use of the word resilience is "resilience from" or "resilient to". This usage appears in many papers with the implication that resilience concerns the entity, either specific assets or the community which may be subjected to the threat of some kind of disaster, having the strength to withstand the impact of the threat and return to normal life soon. Examples of this usage, which do not have additional explanation of how this resilience is achieved or a detailed statement of the author's intent with respect to is are found in (Eggleston and Koob 2004; Shaw, Gupta, and Sarma 2003; Yeo 2003; AusAID 2002; "Reports Mainstreaming disaster risk management: a development for the Pacific small island developing states" 2007; Dufty 2008; Henderson and Ginger 2008; Lambley and Cordery 1997; Arthur, Schofield, and Cechet 2008; Paton, Johnston, Smith, et al. 2001; Enarson and Fordham 2001; Goodyear 2000; Dore and Etkin 2000; McEntire 2000; Chambers 2011; Rothery 2005).

A similar concept is conveyed in (Sullivan 2003a) in the discussion of the idea of inherent resilience to threat. The idea of resilience involving a variety of levels of capacity in the community as the outcome of resistance to the threat is conveyed (Paton, Smith, and Johnston 2005).

Resilience used in a general sense

A large number of the usages of "resilience" appear to be in constructs which suggest that it is used in a general English language sense, to indicate some kind of strength to deal with adversity, with the connotation of being a desirable good in its own right (Aryal and Dobson 2011; Posetti and Lo 2012; Lahey 2012; "'Disaster mapper' designed to help build student resilience" 2012; "Before the storm" 2012; Thornton 2012; Taylor 2001; Kay 2011; Taylor et al. 2011; "Ministerial council for police and emergency management communique Canberra, 26 November 2010" 2011; Cooper 2011; McRae and Sharples 2011; Dufty 2011; Sheehan 2011; Lambley 1998; Powell 1998; Salter 1998-99; Kouzmin and Korac-Kakabadse 1999; McEntire 1999; Bayman et al. 2000; Lunn 2000; Rossi 2000; McGee and Young 2001; Paton, Johnston, Bebbington, et al. 2001; Paton, Johnston, Smith, et al. 2001; Twigg and Steiner 2001; "Communique" 2008a; Pearce 2008; Salter 1995, 1995/96; Granot 1996; May 1997; Buckle, Brown, and Dickinson 1998; Berry and King 1998; Holgate and Di Pietro 2007; Esplin 2007; Paton et al. 2008; Wells and Edwards 2004; Gurtner 2004; Eyre 2004; Goodin and O'Neill 2005; Webster 2006; Watson 2006; King, Goudie, and Dominey-Howes 2006; Nicholls 2006; Haynes 2006; Handmer and Choong 2006; Pearce 2007; Brown 2007; Arnold 2002; Juratowitch,

Daly, and Smith 2002; Taylor 2003).This usage extends with some authors who present the idea that resilience exists in a form which can be referred to meaningfully with the quantitative notion of "more", and similar qualifying terms (Sullivan 2003b; "Communique" 2008b; Handmer and Hillman 2004; Keys 2006; Silberbauer 2003; Abrahams 2004; Yates and Anderson-Berry 2004; Briceno 2004; Laurence 2004; Mearns 2004; Paul 1998-99).

Uses of "resilience" in proper names of entities

There are several organisations which include resilience in the organisation name. In this case the word "resilient" appears in the text as part of a compound word proper noun and does not indicate any usage of the concept of resilience by the author.

There were two uses of "London Resilience", an organisation with the charge of making London more resilient. There were two uses of "Resilient New Zealand", referring to an organisation. There was one reference to "Community Safety and Resilience", referring to a concept as a named entity. Twenty sources used "National Strategy for Disaster Resilience", in reference to an Australian national policy document. Two authors used "Natural Disaster Resilience Program". One reference used "Resilient Organisations" as the name of a research funding scheme.

Uses of "resilience" in book notices and reviews

Eight book reviews and notices are classified here as incidental uses of the word "resilience" because they are very short items and contain a mix of content from the author of the book and the author of the notice or review, thereby making it difficult to discern the intended meaning of the word.

Uses of "resilience" in general notices

In its function as an organ of the Attorney General's Department *AJEM* contains a number of notices of a general kind, some of which contain the word "resilience". The inclusion of the word "resilience" in a brief notice is not analysed since there is, usually, insufficient context to use to infer meaning. There were 12 notices in the journal containing "resilience".

Uses of "resilience" in Conference Notices

In its function as an organ of the Attorney General's Department *AJEM* contains a number of notices of relevant conferences. Many of these notices use the word "resilience" as a topic describing the material to be presented or the possible topics of papers in a call for papers. This type of usage of "resilience" does not convey depth of meaning, and so is not discussed in detail, but the appearance of this usage over time does provide an historical view of the usage of "resilience" as a term of interest in the community. The total number of these references was 11.

Uses of "resilience" in reference lists only

Fifteen authors refer to a source which includes the word "resilience" in the citation, but do not use the word "resilience" in the text of their own contribution.

Uses of "resilience" in author affiliations only

Six articles used the word "resilience" only in naming the entity to which an author was affiliated.

CONCLUSIONS

The discussion of the usage of "resilience" in the two communities, in engineering and in the emergency management community, reflects a fundamentally different usage. The engineering community has only recently shifted usage from a general metaphorical form to a form which enables or guides specific action. This is exemplified in the very recent work described in the first part of this paper showing how the idea of resilience can be transformed into tools which would guide engineered system developers to explore and tease out the ideas that they have with respect to guiding the specification of the proposed engineered system. The essence of this approach is that useful guidance in relation to design of an engineered system requires identification of the potential threats and specification of acceptable, reasonable or desirable outcomes in the event that such a threat actually appears and affects the system. The engineering perspective is that the system designed and developed is a significant asset, intended to last for a reasonably long service life, and that it is difficult to change after construction. The fact that it is difficult to change the system demands that it be made right during development.

The engineered system includes both the equipment items which could be shipped from a developer/supplier to the user and the designed aspects of the situation of deployment, such as the organisational design required to effectively use the engineered system. The asset and the surrounding elements which enable it to be useful constitute the system which is designed, and also the system which is subjected to a variety of threats, and which must appropriately, as defined by the system specification, respond to those threats.

The usage of "resilience" in the emergency management community is still, clearly, in the metaphorical stage, as stated by Rogers (2011). This provides a danger of miscommunication as authors may have one intent and readers may interpret a different meaning. The effect of such a fuzziness of communication is that there is serious risk that action taken around the concept of resilience will be inadequate, with either conflicting overlaps or absences of action, leading to outcomes evidencing less adequate resilience than for which anyone would hope.

The usage of "resilience" in *AJEM* evidences a number of threads, most of which are not major items of contribution, but are part of the facts leading to this conclusion. But there are some major contributions:

- Resilience is a property of a community, that is, the whole life situation including the people and their relationships and the assets they have available are the source of whatever resilience may be present.
- Resilience is concerned with the restoration of the community as closely as possible to its former state of life, including relationships and economic activity, and all the community things necessary to enable that state of life, after the impact of a threat.
- One of the uses of "resilience" concerned the toughening of the community system to withstand the impact of certain threats. This usage parallels the engineering Class 1 response of a system to a threat. This is achievable for threats of up to some magnitude and of defined types, but is impractical for all threats of all magnitudes.
- Since community systems include engineered assets, the engineering application of the resilience metaphor in the specification of acceptable outcomes for a matrix of threat types and magnitudes will inform the design of the assets, through specification.

By combining recent work in the application of the metaphor of "resilience" in engineering to enable tangible responses to what is otherwise a grand rhetorical metaphor with the concerns of the emergency management sector it should be possible to improve community preparedness for threats of diverse kinds, leading to a safer and better life for the community and its members. The path to combination of the perspectives is to develop methods of identifying relevant threat types and magnitudes to guide the design of community development, and the distribution of assistive assets to address needs crated by threat events, in order enable planned levels and timetables of recovery from the threats to be achieved.

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