MODELLING THE IMPACT OF EXTREME WEATHER EVENTS ON HEALTHCARE INFRASTRUCTURE USING RICH PICTURE DIAGRAMS

Denny McGeorge[1], Vivien W. Chow, Jane Carthey and Martin Loosemore

University of New South Wales, The Faculty of the Built Environment, Sydney, NSW 2052, Australia.

Healthcare infrastructure for a community comprises not only its hospital but also many other related facilities such as primary care clinics, community health centres, rural nursing posts, aged care centres, etc. These facilities form a complex set of relationships which need to work collectively for an effective response to climate-change related extreme weather events such as floods and storms. The aim of this research is to develop a conceptual understanding of the dynamic relationships of hospital facilities before, during and after an extreme weather event. This is an essential step in framing a systems model that will assist facility managers to maintain critical healthcare infrastructure during an emergency. Rich Picture Diagrams (RPDs) were used to map relationships between critical healthcare infrastructure components such as the base hospital; access roads; aged care facilities and remotely located supplies. The rich information on the inter-organisational, system and governance complexities associated with responding to extreme weather events was obtained from three hospital case studies (two in Australia and one in New Zealand). The main finding of this research is that RPDs have considerable potential in the development of soft systems models which will assist decision takers involved in the design and management of healthcare infrastructure particularly in the context of extreme weather events. The soft systems methodology which underpins this research challenges the conventional view of what constitutes a 'facility' and consequently has important implications for those constructing and managing facilities.

Keywords: extreme weather events, facilities management, health infrastructure, modelling, rich picture diagrams.

INTRODUCTION

While many organisational dimensions of healthcare delivery are being researched in the context of climate change (McCaughrin *et al.*, 2003; Bonnett *et al.*, 2007; Lalonde, 2007), physical healthcare infrastructure has been relatively neglected. The importance of addressing this deficiency was acknowledged by the Australian Science Engineering and Innovation Council (PMSEIC Independent Working Group, 2007) and by the Council of Australian Governments when they recommended that Australian governments should give priority to developing climate change adaptation strategies for Australia's health infrastructure (Council of Australian Governments, 2007). Given the age of Australian and New Zealand healthcare infrastructure, they recognised that extreme weather events are likely to create increasing challenging physical and patient-related demands which were not envisaged in original hospital

[1] denny.mcgeorge@unsw.edu.au

McGeorge, D, Chow, V W, Carthey, J and Loosemore, M (2011) Modelling the impact of extreme weather events on healthcare infrastructure using rich picture diagrams *In:* Egbu, C. and Lou, E.C.W. (Eds.) *Procs 27th Annual ARCOM Conference,* 5-7 September 2011, Bristol, UK, Association of Researchers in Construction Management, 973-981.

designs. This is clearly evident in the many recorded instances of hospital buildings and their surrounding infrastructure failing to support effective healthcare delivery during such events. For example, it is well documented that in 2006, Tropical Cyclone Larry forced the closure of numerous local hospitals in Queensland (Queensland Government, 2006) and that in 2007 during floods in the Hunter Valley in New South Wales, some hospitals were without power for almost two days and suffered from significant damage to grounds and roofs (Hunter New England NSW Health, 2007). In 2005, the Sydney heat waves affected the elderly and other vulnerable populations such as the obese and chronically ill, causing greater numbers of hospital admissions, and intensifying stress on the existing infrastructure which generally had insufficient surge capacity to cope with this increased demand and changed admission profiles. More recently, in early 2011, the example of the evacuation of both Cairns Base and Cairns Private Hospitals in the face of Cyclone Yasi (Miles, 2011) is a further graphic example of the increasing pressure on facilities caused by extreme weather events.

A mapping approach was adopted to obtain an understanding of the complex interactions which typically occur in regional healthcare infrastructure in both normal and abnormal conditions, as part of the process of developing effective adaption strategies. Our objective is to propose not only technical solutions to improve resilience but also to establishing a conceptual understanding of the currently poorly understood relationships between multiple health infrastructure stakeholders and the importance of collective action among divergent interests as they come together in responding to an extreme weather event.

There is no doubt that modelling healthcare involves considerable complexity, irrespective of whether the system being modelled is organisational or physical, or the interplay between the two. Becker and Carthey have described healthcare systems as a tangled web of interdependencies and make the point that because problems with healthcare are systemic, rather than being caused by any single factor, there is rarely a simple solution (Becker and Carthey, 2007). Referring specifically to the Australian context, the Forster Review also makes this point quite clearly (Forster, 2005). Numerous other publications relating to modelling healthcare systems also place much emphasis on the complex nature of the system being modelled (Janis, 1988; Widdowson, 2004).

HEALTHCARE MODELLING

Most of the focus on research on modelling health care would appear to be on the organisational aspects of service delivery as opposed to the interplay between organisational activity and the physical infrastructure (which is our main area of concern). For example Tan *et al.,* describe how complex adaptive system theory (CAS) can be applied to the design of future-orientated health care and services delivery systems (Tan *et al.,* 2005). Their exploration however relates only to the ‘people’ aspect and ignores the physical infrastructure in which the service delivery systems operate. Indeed it would appear that surprisingly, little research has been undertaken on the relationship of buildings to organisations and organisational effectiveness (Canter, 2008). In essence, building users are largely unaware of the influence which buildings have on their day-to-day activities (Zimring *et al.,* 2005). Indeed it might even be argued that if building users are unaware of a building’s contribution to their operational activities then this is a tribute to a well designed and well managed building. There is however no doubt that a number of inter-dependencies exist between building users and buildings. Markus *et al.,* make the obvious but telling remark that 'buildings are for people. People pay for them; people use them; people design them' (Markus *et al.,* 1972:1). In other words it would be ill advised to consider buildings in isolation from their users or conversely to consider users in isolation from buildings.

METHODOLOGY

A multiple case study approach was adopted for this study as case studies were considered to be an appropriate way to study sub system interdependencies within a complex open system such as the healthcare system. Dooley noted that '...only after the researcher has observed similar phenomena in multiple settings will confirmation or disconfirmation of the new theory begin to take shape and gain substance' (Dooley, 2002: 336). Understanding the interdependent sub systems that need to interact effectively to enable a hospital to respond to extreme weather events requires not only an appreciation of building related issues but also an appreciation the interaction with building users and the built environment. A hospital is a complex organisation with many diverse stakeholders and functions which combine to deliver appropriate health services to a community. Responses to extreme weather events are similarly complex and involve the interplay of many economic, social, organisational, political and cultural considerations which can only be explored fully using a case study approach (Yin, 2009).

Case study data was collected using a proprietary system called "Risk and Opportunities Management System" (ROMS, 2011). Within a structured format, the selected case study focus groups were encouraged to identify and assess the risks and opportunities relating to climate change. Each health organisation's key stakeholders were brought together to review past events they had experienced and to use such knowledge in developing controls for managing responses to similar future events.

Transcripts of the workshops were then analysed and Rich Picture Diagram (RPD) methodology was used to map the interplay of the many interdependent subsystems identified in each case study workshop. The RPD technique has been defined by Patching (1990) as a pictorial summary of the actual situation in the "systems world" based on enquiries or observations of the "real world" (Patching 1990). In essence, a RPD is a pictorial multi-layered representation of the real world using symbols to represent sub-systems and their relationships (of different types – communications, dependencies etc) within a defined system boundary.

CONTEXT: THE CASE STUDIES

The case studies (see Table 1) were chosen on the basis of a past history of extreme weather and our research partners' perceptions of the pivotal role of these facilities in providing care to their communities.

Table 1: Brief description of case studies- for expanded description see Carthey et al., (2010)

Case study	Description
1. Coffs Harbour Base Hospital	Coffs Harbour Base Hospital is the largest hospital on the North Coast of NSW and is the Area's major referral hospital. Many other health facilities rely on this hospital in the case of a major disaster. The hospital serves a population of about 100,000. Coffs Harbour is classified as a sub-tropical area with warm to hot summers and mild winters and, due to its geographical location, flooding and storms are relatively common. In May 2009 floods resulted in the evacuation of 148 residents from local aged care facilities and in November 2009, Coffs Harbour was again declared a natural disaster zone following flooding which caused damage to local infrastructure.

Case study	Description
2. Ceduna District Health Services	Ceduna District Health Services provides the primary healthcare to the residents of Ceduna in South Australia around the far west coast of Adelaide. Ceduna has a population of 3,500 people and 24% of the population are Aboriginal and Torres Strait Islanders. Ceduna is an arid zone with hot dry summers and very high temperatures. Although extreme heat is common in Ceduna, periods of prolonged temperatures in the mid 40 degrees Celsius range has increased in frequency and intensity in recent years.
3. Whangarei Hospital	The city of Whangarei is located 160km from Auckland, New Zealand and is the largest urban centre in the Northland region, serving a population of about 75,000. The Northland Region has a sub-tropical climate with warm humid summers and mild winters. In summer and autumn, storms of tropical origin may bring high winds and heavy rainfall from the east or northeast. In 2007, Whangarei had its wettest winter since 1973 producing widespread severe flooding and landslips throughout much of Northland. Many buildings were washed away, homes flooded, and many motorists stranded on flooded roads. Whangarei hospital was forced to use emergency generators, water supplies were affected and thousands of residents were without phones and electricity.

DATA COLLECTION

Using ROMS a series of independent focus group sessions were conducted with key stakeholders who would be involved in the response to an extreme weather event. These stakeholders included facility managers, business managers, emergency staff, nurses, clinicians, hospital administrators, community health specialists etc. In the ROMS workshops stakeholders are asked to first agree key objectives in responding to an extreme weather event, then to identify the risks and opportunities that may prevent the objectives been met (or enhance them in the case of opportunities), and finally to brainstorm strategies to minimise risks and maximise opportunities. In our subsequent analysis of the transcripts of each of these sessions, it quickly became apparent that many of the suggested issues and strategies were highly interdependent, and that the resolution of some depended on initial action by outside agencies (i.e. other parts of the system) whilst others required subsequent or concurrent action to be undertaken by either internal or external stakeholders. Additionally, some controls had a particularly strong impact that appeared to aid in the success of many other controls.

Although we agree with Sutrisna and Barrett that RPDs can never be value-free (Sutrisna and Barrett, 2007) we also believe that managing the focus group discussions using the structured approach of ROMS (Loosemore *et al.*, 2009) minimised potential bias from this affect in the data collection process. However, it should be noted that despite this rigour, we were also mindful of the need to avoid ‘groupthink’ which could have biased the data; thus the focus group sessions were carefully managed to prevent this from occurring. Groupthink occurs when a sense of cohesion develops within a group to stifle expressions of individual opinions and force people to conform to group norms (Janis, 1988). This effect is particularly strong when people are talking about real-life responses to past potentially sensitive events such as those caused by extreme weather, which could lead to the blaming of one or more parties. For this reason, the focus-group discussions were carefully structured to avoid any reference to issues of success or failure.

The ROMS structured approach also ensured uniformity in the order of discussions which in turn facilitated easier analysis. The strength of the ROMS focus-groups was their ability to provide insights into the participants’ knowledge, largely based on past experience, regarding the likely risks and opportunities posed by different types of extreme weather events and the identification of a range of potential strategies to mitigate risks and maximise opportunities respectively. Within the detailed and semi structured discussions of risks and opportunities and control strategies that occurred in these intensive one-day workshops, many references were made to other actors and it is these references which became the focus of our analysis that underpinned the construction of the RPDs. The flexibility of the focus group approach was derived from its ability to explore unexpected leads which emerged during the group discussions, enabling deeper insights into peoples' attitudes, beliefs and feelings about inter-relationships and dependencies. By cross referencing these multi-stakeholder accounts, we were able to construct a more accurate picture of what these dependencies and relationships were likely to be in practice.

Finally, although the focus group participants were not specifically questioned as to the components of the system, the identification of these components clearly emerged through the subsequent analysis of the transcripts of the group discussions. This *ex post facto* approach is recommended by Platt and Warwick who, in explaining the use of RPDs state that 'the rich picture should not be used as a tool to communicate with the client... the rich picture is a way of consolidating understanding of the problem situation. This reduces the possibility of opposing perceptions of the real world hindering the modelling process later on' (Platt and Warwick, 1995: 20).

RESULTS

A typical rich picture diagram for Case Study 1 is depicted in Figure 1. Physically the system encompasses a large area with some components of the system being widely dispersed with, for example, one component (hospital stores) being a distance of some 400 kilometres from the base hospital. The RPD does not however represent physical distance between components but rather the degree of connectivity and interdependencies between system components although there is a reasonable probability that components which are widely physically separated are likely to have weaker connections than those components which are physically close and are likely to have a strong interdependency.

In order to identify component interdependencies from the ROMS focus groups, we analysed co-occurrences of comments from our focus group participants using a pattern recognition technique as suggested by Guest and McLennan (Guest and McLennan, 2003), and mapped these correlations using a single pointed arrow. For example, outside contractors depend on the road to access the hospital, which in turn is dependent on the roads and traffic authority to maintain the road and keep it functional.

The RPD shown in Figure 1 provided a method for understanding the data collected by making the data accessible, legible and manageable. The diagram can be explained by examining a single factor and follow the number of arrows that point to or away from it. For example, a large number of arrows pointing *away* from 'patients' means that this component is dependent on a number of other components. Conversely, the amount of arrows pointing *towards* the hospital building illustrates the dependency of these components on the hospital facility.

In terms of the mechanics of the production of RPDs, Sutrisna and Barrett note that there are no universal standards or formal techniques (Sutrisna and Barrett, 2007). Our use of RPDs was to some extent similar to Sutrisna and Barretts' cross case study comparisons and, like them, we found it useful to standardise the RPD symbols to represent the components of the system in order to achieve a degree of consistency. Sutrisna and Barrett cite the caveat from Checkland and Scholes that RPDs have to be considered idiosyncratic in that they show the preoccupations of their compilers to express relationships and value judgements by finding/using certain symbols to convey the correct “feel” of the situations (Checkland and Scholes, 2005).

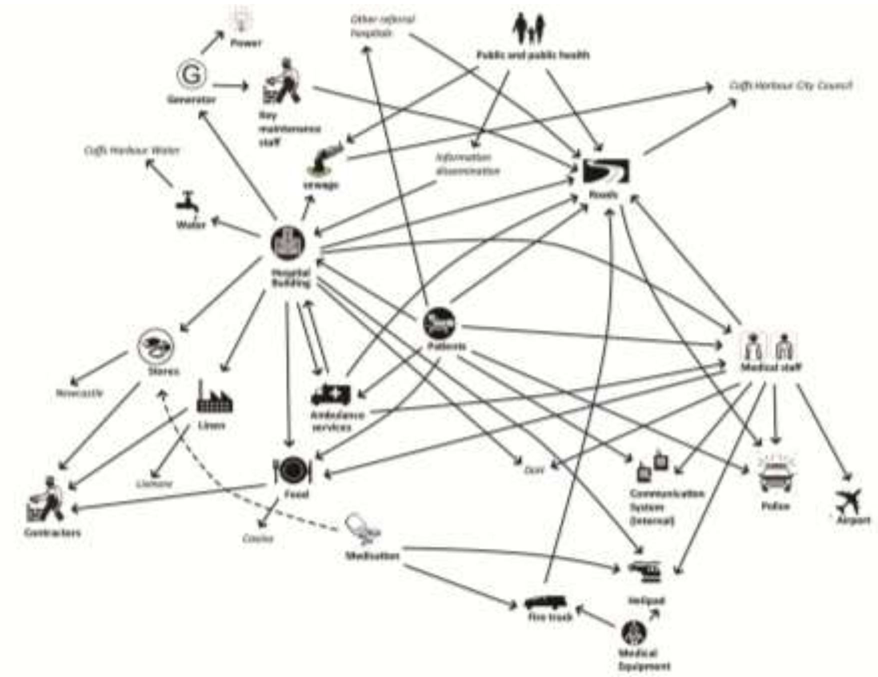

Figure 1 Rich picture diagram of Case Study 1 during normal weather conditions

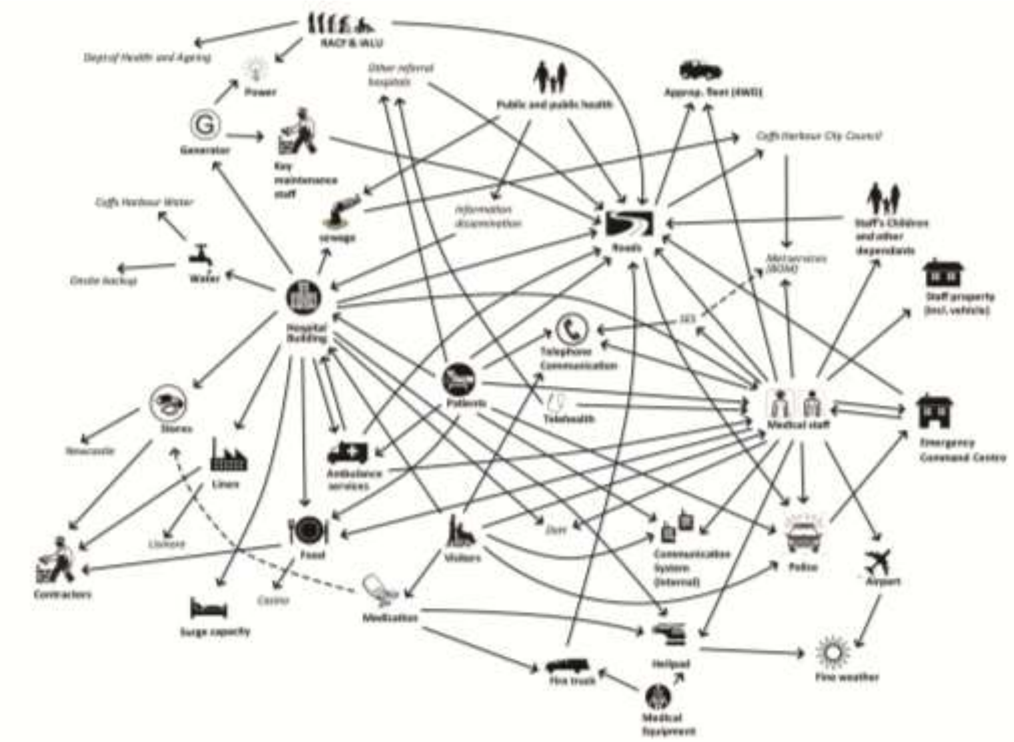

Figure 2 Rich picture diagram of Case Study 1 during and after an extreme weather event

Figures 1 and 2 illustrate Case Study 1 under normal weather conditions and during and after an extreme weather event. It is interesting to note that generally during an extreme weather event the number of system components increases and the inter-relationship between components alters. For example in an emergency situation the residents of an aged care facility may have to be evacuated to the acute hospital (see Figure 2). The fact that an aged care facility may be privately owned and would not normally come under the purview of hospital management is overridden by the need to provide healthcare in time of need. Other facilities such as emergency command centres and staff property also introduce components which are additional to the norm. As the name implies emergency command centres only come into play during an extreme weather event or similar crisis situation. Staff property in Case Study 1 refers to the loss of 90 cars which were inundated in a staff car park which had been design as a water retention area.

Figures 1 and 2 are provided by way of a sample illustration as to how RPDs can be used as a tool to interpret systems under varying sets of conditions. RPDs were also used in this research project for cross-case analysis but these findings are not presented in this paper as the purpose of this paper is to explain the use of RPDs as a means of gaining an insight into the complexities of healthcare infrastructure.

CONCLUSIONS

Our challenge, in this research study, was to focus on the physical aspects of healthcare infrastructure whilst at the same time being mindful of the needs of the numerous stakeholders who depend on the facilities. We have been at pains to emphasise the complex and interactive nature of healthcare infrastructure particularly when subjected to the shock of an extreme weather event. We have also placed considerable emphasise on the dangers of considering the built environment in isolation from the building users. In doing so we are in accord with the International Facility Management Association (IFMA) who have defined facility management as ‘a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology’(International Facility Management Association 2011). The output from the case study focus group sessions reflect the comprehensive nature of IFMA’s definition and the rich picture diagrams illustrate the complexity of the process.

Although we note that the observed systems operate within a broader political policy framework determined by state and the Federal Government we have not attempted, at this juncture, to include these variables within the boundaries of our system. We do however recognise that this policy framework also affects many of other components of the system including for example road traffic authorities (road funding determinations); aged care facility funding policies and market strategies; the state of the general economy, etc, We have also argued that the Rich Picture Diagram approach, with its roots in Soft Systems Methodology, is a useful tool in providing clarity in what could otherwise be an information overload. The general philosophy underpinning the technique is that its application is as a ‘sense making’ rather than a predictive tool.

The rationale for this research is that an understanding of how to create and manage resilient healthcare infrastructure depends, in part, on developing a conceptual understanding of the complex relationships between the various components of a healthcare system which includes emergency services and command centres; off-campus hospital supplies; polyclinics; aged care facilities etc. Our argument is that the

RPD approach which was adopted goes someway to providing an insight into a highly complex and dynamic system and as such brings a fresh perspective on the role of the design, construction and management of healthcare facilities particularly in terms of the new challenges being imposed on both on buildings and people by extreme weather events.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution of our partners in this research: Prof Andy Pitman, Co-director of the Climate Change Research Centre at UNSW; Prof Tony McMichael and Dr Keith Dear, National Centre for Epidemiology and Population Health at ANU; Mr Mark Meurisse of Palisade Asia-Pacific Pty Limited; and our industry partners NSW Department of Health, Government of South Australia Department of Health and New Zealand Ministry of Health.

REFERENCES

Becker, F and Carthey, J (2007), “Evidence Based Healthcare Facility Design: Key Issues in a Collaborative Process”, *Interdisciplinarity in Built Environment Procurement CIB WO92 Symposium*”, 23-26 September 2007, University of Newcastle, Australia.

Bonnett, C. J., Peery, B. N., Cantrill, S. V., Pons, P. T., Haukoos, J. S., McVaney, K. E. and Colwell, C. B. (2007), “Surge capacity: a proposed conceptual framework”, *The American Journal of Emergency Medicine*, **25**(3), 297-306.

Canter, D. (2008), “Do we need a metatheory of the built environment?”, *Building Research & Information*, **36**(6), 663-667.

Carthey, J., Loosemore, M., Chandra, V. and Chand, A. (2010), “The Implications of Extreme Weather Events for Hospital Design and Facilities Management: A Case Study Approach”, *RICS Research conference COBRA 2010*, 2-3 September 2010, Paris, France.

Checkland, P. B. and Scholes, J. (2005), *Soft Systems Methodology in Action*, Wiley, Chichester, UK.

Council of Australian Governments (2007), *National Climate Change Adaptation Framework*, COAG, Canberra, Australia.

Dooley, L. M. (2002), “Case Study Research and Theory Building”, *Advances in Developing Human Resources*, **4**(3), 335-354.

Forster, P. (2005), *Queensland Health Systems Review Final Report*, The Consultancy Bureau, Brisbane, Austarlia.

Guest, G. and McLennan, E. (2003), “Distinguishing the Trees from the Forest: Applying Cluster Analysis to Thematic Qualitative Data”, *Field Methods*, **15(**2), 186-201.

Hunter New England NSW Health (2007), *Storm devastation brings out the best in us*, HNE Health Matters”, Edition 20, June/July, http://www.hnehealth.nsw.gov.au/__data/assets/pdf_file/0014/40271/June-July_special_issue.pdf [Date accessed 15 April 2011].

International Facility Management Association (2011), *What is FM? Definition of Facility Management*, http://www.ifma.org/resources/what-is-fm.htm [Date accessed 21 June 2011].

Janis, I. L. (1988), *Groupthink in behavior in organizations—An experiential approach*, 4ed., Irwin Homewood, Urbana, Illinois, USA.

Lalonde, C. (2007), "Primary healthcare organizations facing a disaster: the Quebec experience", *Disaster Prevention and Management*, **16**(1), 42-55.

Loosemore, M., Carthey, J., Chandra, V. and Chand, A. M. (2009), "Risk Management of Extreme Weather Events: A Case Study of Coffs Harbour Base Hospital, Australia", in Egbu, C. O. (Ed.), *26th Annual ARCOM Conference*, 6-8 September 2010, Leeds, UK. Association of Researchers in Construction Management, **2**, 1239-1246.

Markus, T. A., Whyman, P., Morgan, J., Whitton, D., Maver, T., Canter, D. and Fleming, J. (1972), *Building Performance*, Applied Science Publishers Ltd., London, UK.

Miles, J. (2011), *Cairns hospital open again after Cyclone Yasi*, Courier Mail. http://www.couriermail.com.au/news/queensland/cairns-hospital-open-again-after-cyclone-yasi/story-e6freoof-1225999549260 [Date accessed 19 April 2011].

McCaughrin, W. C., Mattammal, M. and Hixon, A.S. (2003), "Perfect storm: Organizational management of patient care under natural disaster conditions", *Journal of Healthcare Management*, **48**(5), 295-308.

Patching, D. (1990), *Practical Soft Systems Analysis*, Pitman Publishing, London, UK.

Platt, A. and Warwick, S. (1995), "Review of soft systems methodolgy", *Industrial Management & Data Systems*, **95**(4), 19-21.

PMSEIC Independent Working Group (2007), *Climate Change in Australia: Regional Impacts and Adaptation – Managing the Risk for Australia*, Report Prepared for the Prime Minister's Science, Engineering and Innovation Council, Canberra, Australia.

Queensland Government (2006), *Tropical Cyclone Larry Report 1430Hrs 20/03/2006*, http://www.disaster.qld.gov.au/news/view.asp?id=1274 [Date accessed 15 April 2011].

ROMS (2011), *Risk and opportunity management system*, http://www.risk-opportunity.com [Date accessed 19 July 2011].

Sutrisna, M. and Barrett, P. (2007), "Applying rich picture diagrams to model case studies of construction projects", *Engineering, Construction and Architectural Management*, **14**(2), 164-179.

Tan J., Wen, H. J. and Awad, N. (2005), "Health care and services delivery systems as complex adaptive systems", *Association for Computing Machinery (ACM)*, **48**(5), 36-44.

Widdowson, H. G. (2004), *Text, Context and Pretext*, Blackwell Publishing, Oxford, UK.

Yin, R. K. (2009), *Case study research : design and methods*, 4th ed., Sage, London.

Zimring, C., Joseph, A., Nicoll, G. L. and Tsepas, S. (2005), "Influences of Building Design and Site Design on Physical Activity: Research and Intervention Opportunities", *American Journal of Preventive Medicine*, **28**(2S2), 186-193.