Disaster Prevention and Management

Assessing displays for supporting strategic emergency management

Thomas J. Huggins Stephen R Hill Robin Peace David M. Johnston

Article information:

To cite this document:
Thomas J. Huggins Stephen R Hill Robin Peace David M. Johnston , (2015),"Assessing displays for supporting strategic emergency management", Disaster Prevention and Management, Vol. 24 Iss 5 pp. 635 - 650
Permanent link to this document:
http://dx.doi.org/10.1108/DPM-05-2015-0100

Assessing displays for supporting strategic emergency management

Thomas J. Huggins
School of People Environment and Planning, Massey University, Wellington, New Zealand
Stephen R. Hill
School of Psychology, Massey University, Wellington, New Zealand
Robin Peace
School of People Environment and Planning, Massey University, Wellington, New Zealand, and
David M. Johnston
School of Psychology, Massey University, Wellington, New Zealand

Received 8 May 2015
Revised 24 July 2015
Accepted 8 August 2015

Abstract

Purpose – Emergency management groups aiming to address community resilience work with complex systems which consist of multiple interacting dynamics. The purpose of this paper is to help ensure that information is displayed in a way which supports strategic performance, to address longer term challenges faced by these groups.

Design/methodology/approach – Ten professional emergency managers completed an online simulation of complex, community resilience related tasks faced in their normal working lives. They responded to either table-or diagram-based information about a relevant emergency management strategy. Responses were rated by academic and practitioner experts using 0-5 point Likert scales.

Findings – Analyses of the expert ratings found that certain components of macrocognitive performance reached large degrees of inter-rater reliability ($\rho = 0.76$, $p = 0.003$; $\rho = 0.58$, $p = 0.03$; $\rho = 0.53$, $p = 0.05$). Current situation awareness increased by an average of 29 per cent in the diagram condition. Prospective amendment quality also increased, by an average of 38 per cent. A small sample size meant that these increases are difficult to generalise.

Research limitations/implications – Extensions of this pilot research could use larger samples and more generic simulation conditions, to increase confidence in the claim that certain displays help improve strategic emergency management planning.

Practical implications – It is recommended that further research continues to focus on current and prospective situational awareness, as measures of strategic emergency management performance which can be reliably expert rated.

Originality/value – This research provides novel methodological considerations for supporting a more strategic approach to emergency management, with a focus on longer term implications.

Keywords Strategy, Complexity, Emergency management, Situation awareness, Research methods, Display

Paper type Research paper

Many humans are living in a world facing the unprecedented challenges of accelerating climate change (Intergovernmental Panel on Climate Change, 2014). This is also a world marked by on-going natural hazard impacts. Despite substantial efforts led by the United Nations International Strategy for Disaster Risk Reduction, financial losses from natural hazard events in 2013 (140,000 million USD) and 2014 (110,000 million USD) have been

Disaster Prevention and Management
Vol. 24 No. 5, 2015
pp. 635-650

0965-3562
DOI 10.1108/DPM-05-2015-0100

roughly equivalent to average losses over the last 30 years (130,000 million USD, inflation adjusted) (MunichRE, 2014). Much of the planet is also affected by complex environmental degradation, implicated in the extinction of 52 per cent of the world's species between 1970 and 2014 (World Wildlife Foundation, 2014). These phenomena have been observed from within what Fiksel (2006) and Patterson *et al.* (2010) described as increasingly complex and interdependent human systems. Cognitive adaptations for working together and resolving longer term issues within the complex domains of climate change, natural hazard impacts, environmental degradation and human societies have never been so necessary.

Emergency management organisations operate at the nexus of many of these contemporary challenges and according to (Gunderson, 2010), are tasked with dealing with a range of complex human-environment interactions. Emergency managers facing these challenges need to be supported with information displays which they can use in their normal working lives. The current pilot research assumed that particular information displays can improve cognitive responses to the long term, complex challenges faced by emergency managers. Pilot research was used to help determine whether experimental methods can be used to assess the influence of richly visual displays on responses to strategic, longer term emergency management issues.

Diehl and Sterman (1995), Kessell and Tversky (2009), Taleb (2010) and Huggins and Jones (2012) highlighted how habitually linear, sequential understandings can limit human interactions amongst a contemporary range of complex interdependencies. Needs for narrative, story-telling coherence (see Klein, 2003) may drive these tendencies to use linear, rather than more holistic or systematic, concepts in developed Western cultural contexts. Schraagen *et al.* (2008) proposed a solution. They defined macrocognition in terms of adapting overly linear thinking to work with non-linear complexity. According to Cooke *et al.* (2013), macrocognition concerns cognitive adaptations within groups, to improve the way they work with many kinds of complex system. Note that for the study of organisations a complex system is assumed to:

(1) […] consist of a large number of elements;
(2) these elements interact dynamically;
(3) these interactions are rich; any element in the system can influence or be influenced by any other;
(4) interactions are non-linear;
(5) interactions are typically short range;
(6) there are positive and negative feedback loops of interactions;
(7) […] are open systems; and
(8) […] operate under conditions far from equilibrium […] (Maguire, 2011, p. 82).

As outlined by Hoffman (2010), the cognitive adaptations constituting macrocognition can include many changes to thinking within groups working in complex domains. These adaptations are considered positive, rather than negative or counter-productive (Schraagen *et al.*, 2008). Cognitive adaptations to complexity can include a range of processes, such as meta-cognition and group flow. However contemporary macrocognitive research focuses on a range of other processes, linked to specific functions: deciding; sense making; planning; adapting; detecting problems; and coordinating (Klein, 2010). Certain theoretical approaches to macrocognition focus on methods which can be used to analyse a range of macrocognitive functions.

Situation awareness

The current pilot research used a theoretical approach to macrocognition called situation awareness which can be broken down into awareness of: causal precedents, current comprehension and future projections concerning a complex situation (Endsley, 1988). According to Endsley (1988, p. 97), these components of performance in complex scenarios can be influenced by many perceived environmental characteristics such as "colour, speed, size, location". Owen *et al.* (2013) helped highlight how these kinds of influences on situation awareness mark the importance of information displays for emergency management performance. They stated that boundary objects are technologies that are used to share information between diverse emergency management collaborators. It follows that many perceived environmental characteristics are mediated by boundary object representations, meaning that people see boundary object displays and not the actual environmental characteristic. Boundary objects can therefore enhance or impede situation awareness, representing impacts on the cognitive performance of emergency management groups.

Boundary objects are rarely provided in text only. Many include rich visual display elements such as colours, form and spatial distribution. The importance of rich visual displays has been reinforced by a critical review of associated research and theory by Tversky (2011), who concluded that such displays can improve thinking about demanding concepts and scenarios. Particular visual displays may also help people to engage with non-linear concepts, even if they would habitually think in terms of more linear, sequential representations. For example, Kessell and Tversky (2009) found that while 60 per cent of their research participants tended to draw cyclical dynamics along a straight line, 80 per cent of the same participants preferred a circular diagram of the same dynamics.

Boundary objects are very similar to the computational mediums considered in the distributed cognition approach to macrocognition. However, as stated by Cooke and Gorman (2010), computational mediums in macrocognitive research are typically assumed to be interpreted in exactly the same way by all potential collaborators. For example, a shallow reef on the computational medium of a naval map is a shallow reef. Any different interpretation of this computational medium is effectively a misinterpretation which could have dire consequences. In an emergency management context, there are many boundary objects which are not uniformly interpreted by all collaborators (Owen *et al.*, 2013).

According to Owen *et al.* (2013), boundary objects are not interpreted or used in the same way by all parties to emergency management. Many hazards communicated as part of emergency management information are interpreted in different ways, by different collaborators, for different purposes. For example, geologists may decide that a map showing sandy soils beneath a coastal community illustrates a substantial earthquake risk. The same map of sandy soils can illustrate the ideal conditions for beach-front development, as a primary concern for property developers. Their local government representatives may also agree with this interpretation. Such diverse interpretations extend to the social and economic data informing emergency management decisions, as outlined in the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015). Displays which communicate this more abstract information can be interpreted even more disparately amongst diverse interests. The potentially diverse interpretations of boundary objects in emergency management led Owen *et al.* (2013) to associate boundary objects with a particular view of situational awareness: distributed situation awareness. According to Stanton *et al.* (2006) this view acknowledges how different situational elements are interpreted in different ways, for different purposes. Situational elements also need to be interpreted over different timeframes, as detailed below.

Strategic vs tactical timeframes

Many emergency managers are tasked with dealing with the longer term consequences of climate change, natural hazard impacts, environmental degradation and/or rapid urban development. However, macrocognitive methods for analysing the role of emergency management displays have mostly been developed with short term, tactical implications in mind. This creates a divide between the demands of making longer term strategic decisions and the short-term focus of extant cognitive research. Examples of a tactical focus in emergency management research include analyses of: critical fire-fighting decisions, by Klein *et al.* (2010); displays for supporting situation awareness during emergency response, by Prasanna (2010); and situation awareness and decision making during emergency response training, by Sinclair *et al.* (2012). As exceptions, Bruneau *et al.* (2003) and McDaniels *et al.* (2008) have outlined the need for decision-support tools which help address much longer term aspects of emergency management such as community resilience in the face of on-going earthquake risk.

Current hypotheses

The current pilot primarily aimed to examine whether an experimental design could detect the influence of a boundary object on macrocognitive performance, in the context of strategic emergency management across a geographic region of New Zealand. Criteria from the NAVSEA (2005) performance testing battery were tested for inter-rater reliability in this markedly strategic domain. These criteria had been used to assess decisions with grave tactical implications during military conflicts, where the quality of decisions was paramount. With reference to Owen *et al.* (2013), the influence of boundary objects may be so profound that they affect decisions with tactical and strategic implications alike. Reflecting a distributed situational awareness approach to longer term emergency management challenges, NAVSEA (2005) criteria were adapted to assess each response to a boundary object as a unique interpretation. There were no unitary model answers. It was hypothesised that responses to strategically focused boundary objects would nonetheless be reliably rated by emergency management experts using this approach.

As part of the primary research aim, the current pilot attempted to test whether an augmented boundary object could support improvements in strategic macrocognitive performance amongst emergency managers. As outlined earlier, highly sequentially linear, text-based displays may do little to support cognitive performance when working with complex systems. It was therefore hypothesised that an augmented, diagram-based boundary object would support a higher level of macrocognitive performance than the status quo, table-based format. This performance would only be assessed using situation awareness measures found to be reliable while testing the first hypothesis outlined above.

Method

Kozlowski and Chao (2012) outlined the value of cognitive experimentation for macrocognition research. They stated that experiments can take a more open approach to information seeking while controlling other, experimentally structured, conditions. For the current pilot research, the phrase "open information seeking" refers to allowing participants to seek information from the same sources that they would in the field. According to Kozlowski and Chao (2012), allowing participants to seek a range of relevant information incorporates stimuli more closely representing the complex demands which those participants would ordinarily have to deal with.

Experimental simulations provide methods for incorporating open information seeking. According to Greenwood (1989), these research designs allow social psychology to respond to criticisms about the artificiality of highly controlled social psychological experiments and findings. Experimental simulation designs represent a balance of structured experimental controls alongside conditions which are less restricted. The second half of this balance is achieved by including elements which are not usually found in laboratory research but which help create immersive realism relevant to specific real-world tasks (Greenwood, 1989). For example, an experimental study of e-mail processing in an office environment would include rather than eliminate conversations and other distractions in the background.

This balance of field and laboratory conditions is how experimental simulations meet the need for open information seeking in macrocognitive research. Unrestricted access to the internet and other information sources can form an important part of experimental simulation realism, especially where these activities are an important aspect of real-life conditions. Relevant research precedents include a range of decision-support tool evaluations. According to Adleman (1991), decision-support tools which are used to display selected information and recommend relevant courses of action in complex scenarios have often been tested in situ. For example, Eguchi *et al.* (1997) tested a decision-support tool with agencies who were responding the Northridge earthquake of 1994.

The current pilot research is focused on information displays, rather than systems which produce the information displayed. Detailed piloting is an indispensable part of developing robust experimental simulations to assess these displays. It is essential to ensure that these experiments simulate the important conditions and demands that would be faced by participants dealing with real world equivalents. This match between experiment and normal working life helps to ensure ecological validity: congruence between experimental conditions and the contexts to which cognitive researchers aim to generalise their analyses (Chaytor and Schmitter-Edgecombe, 2003). This congruence is most likely to be achieved when participant representatives are given the opportunity to comment on successive versions of an experimental protocol. In this way, the ecological validity of an overall design and specific improvements are both addressed before the actual experimental protocol is deployed.

The current pilot research assumes that experimental simulations can stimulate and observe macrocognition in response to realistic conditions. It is also assumed that realistic conditions include boundary objects being used to communicate and adapt actual emergency management strategies. The current experimental simulation design is outlined below, with reference to research precedents which have focused on information systems and planning scenarios within complex domains. Participants, materials, procedures and measures are also outlined.

Research design

There is a clear need to improve strategic responses to many contemporary complexities, as outlined in the introduction to the current paper. However longer term, strategic macrocognition can start to look like a misnomer. It can be much more straightforward to conduct experimental simulations of brief, tactical timeframes, rather than simulating part of an extended series of strategic implications. Strategic equivalents would typically involve more people interacting over longer periods of time, creating extremely complex and resource intensive experiments. Perhaps this is why all studies that Klein (2010) used to illustrate the use of macrocognitive metrics were focused on short-term, tactical conditions. Likewise, the NAVSEA (2005) programme appears to be focused on tactical naval engagements – rather than the longer term intricacies of an entire military deployment. Furthermore, as outlined by Schraagen *et al.* (2008), contemporary understandings of macrocognitive processes and functions originated in the study of time-pressured individuals, in highly tactical scenarios.

The tactical focus of prior research precedents poses methodological and theoretical challenges to those wanting to conduct strategically focused macrocognition research. However, important lessons from tactical research than can still be applied to strategic concerns. Consider three of the macrocognitive functions defined by Klein *et al.* (2010):

Planning: responding to shifting objectives, opportunities, obstacles, occurrences, or trends, and adapting plans that do not adequately address them.

Detecting: detecting events that have changed a situation in unexpected ways and which may now merit new sense making, planning and execution.

Sense making: collating, cross-referencing and structuring information towards highlighting new explanations.

These macrocognitive functions can all be analysed within PlanEx scenarios which, according to Klein (2010), have become an established approach to macrocognitive research. According to Klein (2010, p. 50), PlanEx scenarios require "the participant to prepare a plan […] […] measures are the quality of the plan, the ability of the participant to see the "sweet spot" for leveraging resources, and so on". These scenarios aim to stimulate planning and re-planning behaviour as a response to problems with an original plan (Klein, 2010). The scenarios can fit within an efficient experimental simulation of strategic issues for the following reasons. First, individual contributions to planning or re-planning in the real world are often time-limited due to other workplace demands and document trajectories. It is therefore possible to simulate a re-planning function without extending the timeframe of a strategic scenario *ad infinitum*. Second, an experimental simulation of strategic contributions can continue to focus on macrocognition amongst embedded individuals, without being limited to the purely tactical implications of participants' responses.

Participants

The particularly complex and long term, community resilience approach is commonly concerned with capacities to resist, recover from, adapt to, and mitigate disaster impacts (see Huggins *et al.*, 2015). All six emergency management offices in New Zealand with a named community resilience strategy were therefore invited to participate. These emergency management offices had a total of 20 community resilience personnel and managers. Four of these offices were contacted through a site visit to their headquarters in the months leading up to formal recruitment. One office was contacted by video conference and another by email. Section managers from the offices helped to improve a dummy version of the experimental simulation outlined below. They provided feedback on the pilot research procedure without viewing the actual experimental conditions, to ensure that data collection and analysis would be relevant to their own interests and the working lives of their personnel. Several changes were made to the experimental procedure as a result.

Materials

As outlined by Kapucu (2012), the complexity of many emergency management scenarios creates challenges that cannot be met by agencies and personnel acting in isolation. This is particularly true for emergency management approaches to community resilience which, according to Cutter *et al.* (2010), involve a combination of social, economic, institutional, infrastructural and environmental considerations. Many relevant dynamics need to be measured and then acted upon (Cutter *et al.*, 2010), requiring collaborations both within and between collaborating groups. Actions within these collaborations are often reported in terms of key performance indicators (KPIs), which help gauge an organisation's progress towards key strategic goals.

For the current pilot research, digital displays showing KPIs as part of a regional community resilience strategy were the boundary objects of interest. One of these displays was a diagram used to improve monitoring, evaluation and research surrounding the regional community resilience strategy, as shown in Figure 1. This diagram was constructed using the visual monitoring and evaluation process (Duignan, 2013). For more information about this collaborative process see Huggins *et al.* (2015). The current pilot research compared this rich visual diagram with a text-based table of KPIs based on the table being used by the collaborating practitioners, shown in Figure 2.

Procedure

All participants were asked to access the online simulation from their workplace where possible, to simulate working conditions. Upon accessing the simulation, participants were shown a brief summary of the pilot research. The summary did not outline visual display benefits, to avoid influencing responses. Participants were then asked to proceed through the following screens:

(1) introduction to the scenario, being an e-mail request for advice about KPI results;

(2) a basic introduction to either the diagram or text-based table format, as randomly assigned to each participant;

(3) general advice for interpreting the KPI format;

(4) an introduction to the actual programme KPIs, without performance results; and

(5) the same display, with the addition of actual programme results obtained over a six month period, as shown in Figures 1 and 2.

Each screen was accompanied by a relatively informal explanation of each image, simulating the extended e-mail request for advice. Participants were then asked to compose a reply to their colleague, as prompted by the following request: "This is what the [diagram/table] looks like with group data from the last six months. Please tell me what you think is going wrong". The prompts for responses were:

(1) "Please start a brief e-mail to your colleague about what you think is going wrong".

(2) "Continue the e-mail to your colleague, detailing anything else you want to know. Include details of how you could get this information".

(3) "Assume that you cannot get more information right now. Acting in your current emergency management role, what would you do about what you have noticed?"

Participants were asked to provide their responses in scrolling text entry boxes which did not have a word limit. Either Figure 1 or 2 remained on screen below, while participants entered their responses. At the conclusion of the simulation protocol,

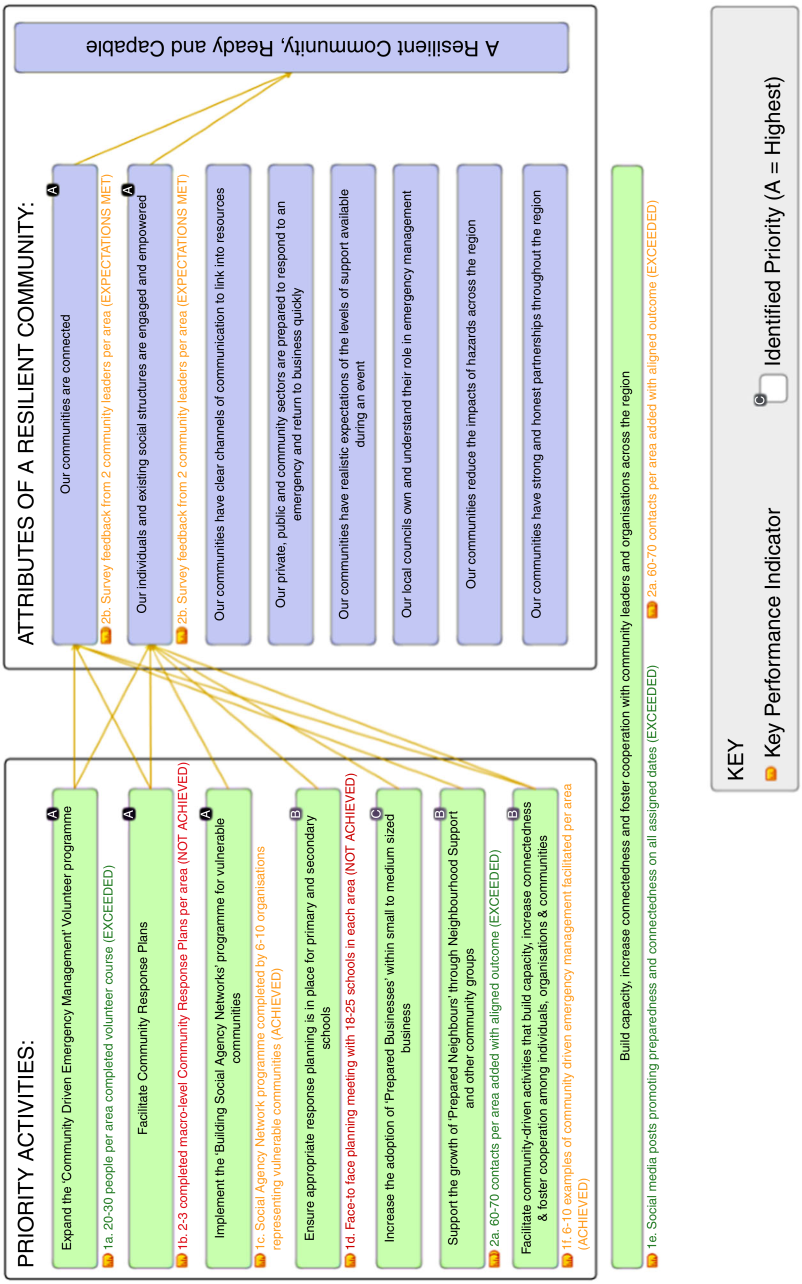

Figure 1.
Rich visual, diagram display of key performance indicators

1. Increase resilience across the region		
a. People completed volunteer course	Achieved: 20/area	Exceeded: 30/area
b. Completed macro-level community response plans	Achieved: 2/area	Exceeded: 3/area
c. Social Agency Network programme completed by organisations representing vulnerable communities	Achieved: 6	Exceeded: 10
d. Face-to face planning meetings with schools	Achieved: 18/area	Exceeded: 25/area
e. Social media posts promoting preparedness and connectedness	Achieved: All assigned dates	Exceeded: Additional dates
f. Examples of community driven emergency management facilitated per area	Achieved: 6/area	Exceeded: 10/area

2. Build capacity, increase connectedness and foster cooperation with community leaders and organisations across the region		
a. Contacts added with aligned outcome	Achieved: 60/area	Exceeded: 70/area
b. Interviews with 2 community leaders per area	Achieved: Expectations met	Exceeded: Expectations exceeded

Figure 2.
Status quo, table display of key performance indicators

participants were asked to identify anything about the KPI display that helped them produce their responses. They were then asked to provide demographic details concerning their age and years of relevant experience. These details represented potential moderating influences, which we aimed to control for by random assignment to experimental conditions. To complete the simulation protocol, all participants then proceeded to a screen which thanked them for their time before giving them the opportunity to enter a draw for a USD 100 Amazon gift voucher.

Performance measures

The current experimental simulation measured differences in macrocognitive performance in response to Figures 1 and 2, within a PlanEx scenario. As outlined in the research design, the macrocognitive functions of interest were: detecting problems, sense making and re-planning. Each of these functions were respectively measured using situation awareness components based on the NAVSEA (2005) performance testing battery, as follows:

1. Antecedent situation awareness: detecting problems with the regional community resilience strategy shown by the KPI display.
2. Current situation awareness: sense making about the way those problems affect the regional community resilience strategy.
3. Prospective situation awareness: re-planning the regional community resilience strategy to reflect a renewed understanding.

Two experts who had been involved in piloting the experimental simulation agreed to complete expert rating scales for each of the simulation responses. One was an internationally renowned expert in community disaster resilience practice, who had recently delivered an online course on the topic to over 1,500 students from a wide variety of international backgrounds. The other expert had an extensive academic background in measuring adaptive capacity components of community resilience. This expert had recently been appointed to head a national science platform for promoting social science research into natural hazards. Both experts were given Likert scales from 0 to 5. The 0 indicated "not at all" or "nil" and 5 indicated "perfectly" or "complete". These scales were used to rate the situational awareness of participant responses in terms of:

1. Participant's awareness of what has happened with the programme (antecedent).
2. Participant's awareness of the implications of what has happened (current).
3. Have they translated awareness into a feasible course of action?
   - Seeking further information? (prospective information seeking).
   - Amending the original strategy and/or indicator framework (prospective re-planning).

Results

Despite a generally high level of engagement with section managers and several reminders, only ten emergency managers completed the experimental simulation. This represented a response rate of 50 per cent. List-wise missing value analysis was used to determine the most probable age of one participant and years of KPI experience for another participant. Using these figures, participants appeared to range from 34 to 57 years old (SD = 6.99). They appeared to have between zero and ten years of display-specific experience for KPIs (SD = 3.91). Outcomes diagram experience ranged from 0 to 0.5 years (SD = 0.16). The emergency management experience of participants is outlined in detail further below.

All simulation responses were analysed by experts, as outlined in the procedure section. Analyses of expert ratings found that one component of situation awareness and two sub-components reached an acceptable level of inter-rater reliability. Ratings for current situation awareness (CSA) had a large intraclass correlation ($\rho = 0.76$, $p = 0.003$), using standards established by Shrout and Fleiss (1979) and Donner and Koval (1980). Ratings of prospective information seeking quality (PISQ) ($\rho = 0.58$, $p = 0.03$) and prospective amendment quality (PAQ) ($\rho = 0.53$, $p = 0.05$) also had large intraclass correlations. Expert-rated antecedent situation awareness did not achieve inter-rater reliability ($\rho = 0.47$, *ns*).

Table I shows mean expert ratings for each of the reliable situation awareness variables: CSA; PISQ; and PAQ. There was a substantial difference between CSA and PAQ between the two conditions. However these differences, of 29 per cent (95 per cent CI 2.74, −0.83) and 38 per cent (95 per cent CI 3.20, −0.95), were not statistically significant. Participants' comments on the display formats were not revealed to expert raters and did not form part of their ratings. The original comment from each set of responses is displayed in the last column of Table I.

An analysis of variance between groups suggested that age and KPI experience had been controlled for by random assignment ($F < 1$). Outcome diagram experience amounted to one participant with six months experience, making this moderator

Condition	CSA	PISQ	PAQ	Un-rated comment on format
Diagram	2.5	0	2	Nil
Diagram	2.5	2.5	3.5	"The red colour stood out :-)"
Diagram	3	3.5	4	"Yes, understanding the linkages helps"
Diagram	3.5	0.5	3	"?"
Diagram	0	0.5	0.5	Nil
Diagram	2	3	3.5	"I think this format is clear and linked. A PS point – I would also ask if the priority order was correct. Maybe increasing the priority of Facilitating Community Driven Activities would then create the right environment to move onto Community Response Plans"
Table	2	0.5	2.5	"Quite liked the fact that if things were met or exceeded they got highlighted; this made it quite easy to read quickly what was working and what wasn't, and where more or different effort may need to be made"
Table	0	0	0	"No"
Table	2	3.5	3	"I could tell where a KPI had not been meet, but not by what margin, and could also not see how close to exceeding they were – e.g., did they visit 17 schools, or get 50 through a volunteer course?"
Table	3	3	2.5	"Highlighted areas help read the KPI format"
Diagram mean	2.25	1.66	2.75	
Table mean	1.75	1.75	2	

Table I. Expert ratings and participant comments on display format by experimental response negligible. Random assignment did not appear to have controlled for emergency management experience ($F(1, 8) = 1.08$, *ns*). An average 7.08 years of experience in the diagram group was almost double the average 3.88 years of experience amongst participants responding to the table display. This factor appeared to have a generally negative influence on implication awareness ($R^2 = 0.431$, *ns*) and strategic change quality ($R^2 = 0.278$, *ns*), which may have attenuated improvements due to display format. However a small sample size meant multivariate analyses were not feasible. This meant the potentially moderating effect of emergency management experience and other demographic variables could not be accurately determined or statistically controlled.

Conclusion

Emergency management groups deal with complex interactions among many dynamic human and environmental systems. The current pilot research aimed to pilot an assumption that certain information displays can improve strategic performance when dealing with related demands. Ten professional emergency managers completed an online simulation of complex, strategic tasks faced in their normal working lives. They responded to either a table- or diagram-based set of information about contributions to a complex emergency management strategy. Responses were rated by emergency management experts using Likert scales from 0 to 5, reflecting components of situation awareness. Results from analyses of these ratings provide fair to tentative support for the two research hypotheses. These results have implications for rating the influence of information displays on strategic emergency management performance. There are certain potentials for further research in this area, as outlined below.

Rating strategic emergency management performance

H1. That situation awareness ratings would achieve inter-rater reliability concerning a strategic scenario, was partially supported.

This hypothesis was an important part of the current pilot research aim because the efficacy of strategic boundary objects are very difficult to test without robust rating scales. Three of four situation awareness components achieved inter-rater reliability, with large intraclass correlations from 0.76 ($p = 0.003$) to 0.58 ($p = 0.03$). Inter-rater reliability is not usually considered to be an integral hypothesis for experimental findings. However it was important that the majority of items in the current set of macrocognitive performance measures were found to be reliable, despite the shift to a more strategic research context.

This finding is particularly important for the field of emergency management, where research has often examined cognitive responses to tactical conditions, involving much shorter-term implications. The current finding, that established tactical metrics can be used to gauge a more strategic approach to macrocognition, is therefore more important than it appears at face value. This finding provides an avenue to interrogate and start improving a self-perpetuating focus on researching short-term, rather than longer term, emergency management objectives.

Rich visual displays may improve strategic emergency management

H2. That a diagram-based boundary object could support a higher level of macrocognitive performance than the status quo table format, was only very tentatively supported by the current results.

A substantial improvement (29 per cent) in CSA was observed amongst responses to the diagram condition. An even more substantial improvement (38 per cent) in PAQ was observed. Even amongst such a small sample, these differences tentatively suggest that the diagram provided more macrocognitive support than the table equivalent.

Participants' comments about the displays themselves suggest that the diagram was more useful due to additional colours, graphic linkages between components, and markers for the priority level of many components. These are rich visual elements which, according to research by Kessell and Tversky (2009) and Huggins and Jones (2012), help avoid limitations of a more sequentially linear, largely text-based display. As noted by two participants, the table display also included a limited number of rich visual elements. Two participants commented on the ease of interpreting highlighted sections of the table. One participant's comment, that these made the table "easy to read quickly", appears related to the speed rather than the quality of responses because this particular response received a fairly mediocre set of expert ratings. It is nonetheless possible that differences in macrocognitive performance would be more marked between the current diagram and a fully text-based equivalent.

Limitations and considerations for further research

A highly specific population of interest and a mediocre response rate appear to have limited the inferential power of the current results. A very small sample of participants meant that observed differences between responses to the diagram and table conditions became equivocal at a 95 per cent confidence level. Likewise, the notable effect of emergency management experience was not able to be specified or controlled for. The current research therefore remains a pilot for further research into how boundary objects can support strategic emergency management.

Future research in this area will benefit from larger samples. These samples can be achieved through using more generic simulation conditions, which apply to much larger groups of potential participants. Repeated measures amongst the same sample of participants can be also used to improve on the size of a data sample, even amongst highly specific groups. Likewise, a higher response rate is likely to be achieved by contacting all participating groups in person, to establish a higher level of trust and interest in the research. These improvements are likely to support more robust statistical analyses of potential changes in strategic performance due to different display formats. Considering inter-rater reliabilities achieved in the current pilot research, it is recommended that further research into strategic macrocognition continues to focus on expert-rated current situation awareness, prospective information seeking quality and prospective amendment quality.

Acknowledgements

The current research was funded by the Earthquake Commission of New Zealand, GNS Science and Massey University. Persons overseeing this funding did not participate in the study design, collection, analysis and interpretation of data, or in the writing and submission of this paper. The research was also supported by non-financial contributions from the Wellington Region Emergency Management Office who provided the KPI displays adapted for the experimental simulation. The current research was conducted within Massey University Human Ethics Committee guidelines and procedures.

References

Adleman, L. (1991), "Experiments, quasi-experiments, and case studies: a review of empirical methods for evaluating decision support systems", *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 21 No. 2, pp. 293-301.

Bruneau, M., Chang, S.E., Eguchi, R.T., Lee, G.C., O'Rourke, T.D., Reinhorn, A.M., Shinozuka, M., Tierney, K., Wallance, W.A. and von Winterfeld, D. (2003), "A framework to quantitatively assess and enhance the seismic resilience of communities", *Earthquake Spectra*, Vol. 19 No. 4, pp. 733-752.

Chaytor, N. and Schmitter-Edgecombe, M. (2003), "The ecological validity of neuropsychological tests: a review of the literature on everyday cognitive skills", *Neuropsychology Review*, Vol. 13 No. 4, pp. 181-197.

Cooke, N.J. and Gorman, J.C. (2010), "The pragmatics of communication-based metrics for measuring macrocognition", in Patterson, E.S. and Miller, J.E. (Eds), *Macrocognition Metrics and Scenarios: Design and Evaluation for Real World Teams*, Ashgate Publishing, Farnham, pp. 161-178.

Cooke, N.J., Gorman, J.C., Myers, C.W. and Duren, J.L. (2013), "Interactive team cognition", *Cognitive Science*, Vol. 37 No. 2, pp. 255-285.

Cutter, S.L., Burton, C.G. and Ermlich, C.T. (2010), "Disaster resilience indicators for benchmarking baseline conditions", *Journal of Homeland Security and Emergency Management*, Vol. 7 No. 1, pp. 1-22.

Diehl, E. and Sterman, J. (1995), "Effects of feedback complexity on dynamic decision making", *Organizational Behaviour and Human Decision Processes*, Vol. 62 No. 2, pp. 198-215.

Donner, A. and Koval, J.T. (1980), "The estimation of intraclass correlation in the analysis of family data", *Biometrics*, Vol. 36 No. 1, pp. 19-25.

Duignan, P. (2013), "Faster monitoring and evaluation (M&E) planning", available at: www.outcomescentral.org/dplan/eval.html (accessed 2 February 2013).

Eguchi, R.T., Goltz, J.D., Selison, H.A., Flores, P.J., Blais, N.C., Heaton, T.H. and Bortugno, E. (1997), "Real-time loss estimation as an emergency response decision support system", *Earthquake Spectra*, Vol. 13 No. 4, pp. 815-832.

Endsley, M.R. (1988), "Design and evaluation for situation awareness enhancement", *Proceedings of the Human Factors Society – 32nd Meeting in November 1988, Human Factors Society, Santa Monica, CA*, pp. 96-101.

Fiksel, J. (2006), "Sustainability and resilience: toward a systems approach", *Sustainability: Science, Practice & Policy*, Vol. 2 No. 2, pp. 14-21.

Greenwood, J.D. (1989), *Explanation and Experiment in Social Psychological Science*, Springer-Verlag, New York, NY.

Gunderson, L. (2010), "Ecological and human community resilience in response to natural disasters", *Ecology and Society*, Vol. 15 No. 2, pp. 18-28.

Hoffman, R.R. (2010), "Some challenges for macrocognitive measurement", in Patterson, E.S. and Miller, J.E. (Eds), *Macrocognition Metrics and Scenarios: Design and Evaluation for Real World Teams*, Ashgate Publishing, Farnham, pp. 11-28.

Huggins, T.J. and Jones, L.M. (2012), "Visually modelling New Zealand conservation strategy: a study of user experiences", *Ecopsychology*, Vol. 4 No. 4, pp. 286-296.

Huggins, T.J., Peace, R., Hill, S.R., Johnston, D.M. and Cuevas, A. (2015), "Visually modelling collaborative research into innovative community disaster resilience practice, strategy and governance", *International Journal of Disaster Risk Science*. doi: 10.1007/s13753-015-0061-6.

Intergovernmental Panel on Climate Change (2014), "Fifth assessment report", Intergovernmental Panel on Climate Change Secretariat, Geneva.

Kapucu, N. (2012), "Disaster and emergency management systems in urban areas", *Cities*, Vol. 29 No. 1, pp. 541-549.

Kessell, A.M. and Tversky, B. (2009), *Thinking About Cycles: Producing Sequences but Preferring Circles*, Stanford University, Stanford, CA.

Klein, G. (2010), "Macrocognitive measures for evaluating cognitive work", in Patterson, E.S. and Miller, J.E. (Eds), *Macrocognition Metrics and Scenarios: Design and Evaluation for Real World Teams*, Ashgate Publishing, Farnham, pp. 47-64.

Klein, G.A., Calderwood, R. and Clinton-Cirocco, A. (2010), "Rapid decision making on the fire ground: the original study plus a postscript", *Journal of Cognitive Engineering and Decision Making*, Vol. 4 No. 3, pp. 186-209.

Klein, K. (2003), "Narrative construction, cognitive processing and health", in Herman, D. (Ed.), *Narrative Theory and the Cognitive Sciences*, Center for the Study of Language and Information, Stanford, CA, pp. 56-84.

Kozlowski, S.W.J. and Chao, G.T. (2012), "Macrocognition, team learning, and team knowledge: origins, emergence and measurement", in Salas, E., Fiore, S.M. and Letsky, M.P. (Eds), *Theories of Team Cognition: Cross-Disciplinary Perspectives*, Routledge, New York, NY, pp. 19-48.

McDaniels, T., Chang, S., Colec, D., Mikawozc, J. and Longstaff, H. (2008), "Fostering resilience to extreme events within infrastructure systems: characterizing decision contexts for mitigation and adaptation", *Global Environmental Change*, Vol. 18 No. 2, pp. 310-318.

Maguire, S. (2011), "Constructing and appreciating complexity", in Allen, P., Maguire, S. and McKelvey, B. (Eds), *The SAGE Handbook of Complexity and Management*, Sage Publications, London, pp. 79-92.

MunichRE (2014), "Global and US natural catastrophes in 2014", available at: www.iii.org/sites/default/files/docs/pdf/munichre-010715.pdf (accessed 2 February 2015).

NAVSEA (2005), *NAVSEA Instruction 3900.8A. Human System Integration (HIS) Policy in Acquisition and Modernization*, Naval Sea Systems Command, Southeast, DC.

Owen, C., Bearman, C., Brooks, B., Chapman, J., Paton, D. and Hossain, L. (2013), "Developing a research framework for complex multi-team coordination in emergency management", *International Journal of Emergency Management*, Vol. 9 No. 1, pp. 1-15.

Patterson, E.S., Miller, J.E., Roth, E.M. and Woods, D.D. (2010), "Preface. Macrocognition: where do we stand?", in Patterson, E.S. and Miller, J.E. (Eds), *Macrocognition Metrics and Scenarios: Design and Evaluation for Real World Teams*, Ashgate Publishing, Farnham, pp. xxiv-xxxi.

Prasanna, R. (2010), "Information systems for supporting fire emergency response" a dissertation in partial fulfilment of the degree of Doctor of Philosophy at Loughborough University, Loughborough University, Loughborough.

Schraagen, J.M., Klein, G. and Hoffman, R. (2008), "The macrocognitive framework of naturalistic decision making", in Schraagen, J.M., Militello, L., Ormerod, T. and Lipshitz, R. (Eds), *Naturalistic Decision Making and Macrocognition*, Ashgate, Aldershot, pp. 3-26.

Shrout, P. and Fleiss, J. (1979), "Intraclass correlations: uses in assessing rater reliability", *Psychological Bulletin*, Vol. 86 No. 2, pp. 420-428.

Sinclair, H., Doyle, E.E., Johnston, D.M. and Paton, D. (2012), "Assessing emergency management training and exercises", *Disaster Prevention and Management*, Vol. 21 No. 4, pp. 507-521.

Stanton, N.A., Stewart, R., Harris, D., Houghton, R.J., Baber, C., McMaster, R., Salmon, P., Hoyled, G., Walkera, G., Younga, M.S., Linselle, M., Dymott, R. and Green, D. (2006), "Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology", *Ergonomics*, Vol. 49 Nos 12-13, pp. 1288-1311.

Taleb, N.N. (2010), *The Black Swan*, 2nd ed., Random House, New York, NY.

Tversky, B. (2011), "Visualizing thought", *Topics in Cognitive Science*, Vol. 3 No. 1, pp. 499-535.

UNISDR (2015), *Sendai Framework for Disaster Risk Reduction 2015-2030*, United Nations Office for Disaster Risk Reduction, Geneva.

World Wildlife Foundation (2014), "Living planet report", World Wildlife Foundation Secretariat, Gland.

Corresponding author
Thomas J. Huggins can be contacted at: t.j.huggins@massey.ac.nz

This article has been cited by:

1. Raj Prasanna, Thomas J. Huggins. 2016. Factors affecting the acceptance of information systems supporting emergency operations centres. *Computers in Human Behavior* **57**, 168-181. [CrossRef]