A DIAGNOSIS OF STATE HIGHWAY ORGANISATIONS' DECISION-MAKING DURING EXTREME EMERGENCY EVENTS

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Abstract: This paper introduces the conceptualization and application of a method to analyse the decision making process of New Zealand's State Highway Organisations (SHO) during extreme events. The aim is to obtain an unbiased and complete overview of the strengths and weaknesses of the current decision making. Procedures and metrics to analyse the Quality of Decision Making (QDM) are proposed, based upon the study of theoretical and practical concepts of decision making processes. QDM analysis was applied to 3 real events and 4 exercises, which have been observed since 2005. The results of the QDM analysis indicate that SHO are capable, experienced and competent in dealing with major disruption or crises that may affect the State Highway Network of New Zealand. SHO have achieved High and Regular levels of resilience in terms of decision making activities during emergency response events and exercises.

1   Introduction

Extreme events present responding organisations with complex and unprecedented situations, having the potential for catastrophic losses and consequences on communities. In crises and or emergency events there is an immediate risk to life, health, property or environment Thus, organisations have to quickly respond to observed and changing conditions. These are mostly different to what personnel are used to deal with on a daily basis, under business-as-usual situations (Fredholm, 1999).

There is limited understanding on how organisations perform decision making in extreme events. Even though a few studies have been observed in recent years (Zografos et al., 2000), empirical evidence and understanding of decision makers are still impaired by complexities observed in real situations. It is often observed through anecdotal evidence that decision makers use their own experience and common sense in order to respond to events.

A particular and critical element of response to extreme events is the roading network. Recent worldwide events (e.g Northridge Earthquake, 1994; Sumatra Earthquake and Tsunami, 2004) have demonstrated that the functionality of road transport networks to respond to emergencies is vital in saving lives and reducing economic impacts as many organisations depend on road transport to conduct its own response activities (AELG, 2005). Road transport networks among other key lifeline utilities (e.g. telecommunications, waste water or sewerage networks or entities that produce and supply water, gas, electricity, petroleum products) are expected to function to the fullest possible extent during and after an emergency event.

This paper introduces the conceptualization and application of a method to analyse the decision making process of New Zealand's State Highway Organisations (SHO) during extreme emergency events. Building upon our previous research efforts (Dantas et al, 2007 and Ferreira et al, 2007), the aim is to obtain an unbiased and complete overview of the strengths and weaknesses of the current decision making.

This paper is divided into 5 sections. After this introduction, a conceptual framework to observe decision making activities is presented. In the third section the analysis method of the decision making performance is described. The fourth section introduces the application of the observation framework and the quality of decision making analysis method applied to a series of case studies in which SHO are the main subject. Finally, conclusions are drawn from the application of the analysis method and the whole experience in observing decision making processes in New Zealand.

2   Quality of Decision Making Analysis

Using the scheme proposed by the Defence Command and Control Research Program, CCRP model (Cheah *et al*., 2000) as the main reference, four interconnected domains of decision making are targeted. They are:

- **Physical domain (D_p)** is the tangible real world where physical and human resources are moved through time and space to attend the range of operations required to respond to the evolving extreme event. Physical domain is also the space where organisations and the physical and communications networks that connect all the organisations involved in the management of the extreme event reside;

- **Information domain (D_i)** is the abstract space where information exists and is collected, created, processed, manipulated, and shared and from where information content and flow are created. The quality of the information depends on the accuracy, timeliness, and relevance of information from all sources. The information domain is the link between the reality of the

physical domain and human perceptions, therefore is formed by the intersection of the physical and cognitive domains;

- **Cognitive domain (D_C)**is identified with the mind of the decision-makers, where individual and organisational collective consciousness exists, where decision maker's knowledge, capabilities, techniques, and procedures reside; and

- **Social domain (D_S)**is the domain where humans interact, exchange information, form shared awareness and understandings, and make collaborative decisions. This is also the domain where culture, set of values, attitudes, and beliefs held and conveyed by leaders to the society reside. It overlaps with the information and cognitive domains, but it is distinct from both. Cognitive activities, by their nature, are individualistic; they occur in the minds of individuals. On the contrary, shared awareness and shared sense-making (the process of going from shared awareness to shared understanding to collaborative decision making) are by definition, a socio-cognitive activity because the individual's cognitive activities are directly impacted by the social nature of the exchange and vice versa.

These domains are linked to decision making tasks and cognitive elements. The next three sub-sections present decision making tasks and cognitive elements, their respective success indicators and vulnerabilities and the procedure to compute the QDM performance levels.

2.1 Decision making tasks and cognitive elements

The key elements under observation are identified and specified for the case of roading organisations facing crises/extreme events. In particular, specific tasks and sub-tasks associated to the Physical and Information domains are listed in Table 1. Similarly for the Cognitive and Social Domains specific cognitive and sub-cognitive elements have been depicted. The observation framework proposed in Table 1 is not intended to be a rigid reference. Alternative and more suitable tasks and cognitive elements can be identified and specified depending on the event under observation. Furthermore, it is emphasized that the tasks and sub-tasks as well as the cognitive and sub-cognitive elements are not expected to be observed as independent events. It is acknowledged that functions of a decision making process are always accomplished concurrently and interactively.

Table 1 - Tasks/sub-tasks to be observed, cognitive/sub-cognitive elements to be investigated during the decision making process.

Domains of Decision making	Tasks	Sub-tasks	Acronyms
PHYSICAL	*Response Actions*	Deployment of Human Resources	**DHR**
		Deployment of Physical Resources	**DPR**
		Temporary Traffic Management	**TTM**
		Damage Assessment and Management	**DAM**
INFORMATION	*Data Processing*	Data collection	**Data C**
		Data analysis, storing, summarising	**Data A**
		Data sharing, disseminating	**Data S**
		Data maintaining, updating	**Data U**
	Communication	Communication intra-organisations	**C_INTRA**
		Communication inter-organisations	**C_INTER**
		Communication with media	**C_MEDIA**
		Communication with public	**C_PUBLIC**
Domains of Decision making	**Cognitive elements**	**Sub-Cognitive elements**	
COGNITIVE	*Situation Awareness*	Perception of the evolving scenario	**Perception**
		Understanding of needs	**Understanding**
		Projection of future	**Projection**
SOCIAL	*Collaboration and Coordination*	Collaboration intra-organisations	**S_ INTRA**
		Collaboration inter-organisations	**S_ INTER**

2.2 Success indicators and vulnerabilities

Specific success indicators are identified for each one of the decision making domains. They are:

- **Physical Domain** (S_P) reflects optimisation of the actions to ensure that the road network is able to function to the fullest possible extent, even though this may be at a reduced level, during the emergency and in the recovery and reconstruction phases. These include:

S_{P1}) minimization of road closures duration and variability;

S_{P2}) maximisation of accessibility to strategic services and places; and

S_{P3}) minimization of response and recovery costs.

They can be assessed by quantifying post-emergency phase costs and the time required to complete the response and recovery phases to the emergency/crisis event or judging qualitatively the identification of priorities and the resource allocation.

- **Information Domain** (S_I) measures the degree of connectivity achieved between the various decision makers in a network-enabled environment and the quality of the information exchanged. These include:

S_{I1}) the degree of connectivity achieved;

S_{I2}) the information richness; and

S_{I3}) the extent of information reach.

The degree of connectivity between the various decision makers can be assessed qualitatively by investigating the characteristics of the interactions between the decision makers. Similarly, the information richness can be assessed qualitatively, as a function of the degree of sharing of various forms of information – visual, audio, multimedia, and tools (Albert and Hayes, 2003). Finally, the extent of information reach can be assessed along the dimensions of whether it facilitates simultaneous, selective, and universal communication

- **Cognitive Domain** (S_C) focuses on the judgement of the decision-makers behaviour in order to understand decision maker's knowledge, capabilities, techniques, and procedures. These comprise:

S_{C1}) the individual situation awareness;

S_{C2}) the level of training and experience; and

S_{C3}) intangibles of leadership and unit cohesion.

Individual situation awareness can be investigated by using ad-hoc questionnaires or interviews targeting the assessment of the perception of evolving scenarios, the understanding of needs, demands and implications and the participants' projection of future. Codified techniques such as the Situation Awareness Global Assessment Technique, SAGAT (Endsley, 1995a and Endsley, 1995b) might also be adapted to suit the needs of the assessment.

- **Social Domain** (S_S) includes the responsiveness to the needs of emergency management agencies and the technical advice provided to leading emergency management agencies and lifeline groups. These include:

S_{S1}) responsiveness to the needs of emergency management agencies;

S_{S2}) technical advice to leading emergency management agencies and lifeline groups; and

S_{S3}) coordination of actions with all involved agencies.

The level of responsiveness and technical advice provided to the emergency management agencies and lifelines groups can be assessed based on the expert judgment after the observation phase. The coordination of actions with all involved agencies can be assessed by quantifying the level of self-synchronisation and of team collaboration achieved. Self-synchronisation measures the capability of low-levels to operate nearly autonomously and to re-task themselves through sharing awareness to achieve strategic and operational objectives in accordance with the high level decision maker's intent. Self-synchronisation

can be investigated by critically analysing the different types of communication exchanged between different levels of decision makers. In the context of roading organisations, self synchronization is investigated by analysing whether or not contractors and consultants are able to work out the details of their response activities as new information about the external situation becomes available, without having to continuously rely on decision makers to provide specific directions. Team collaboration measures the degree and quality of collaboration between the various team members and can be inferred from the analysis of messages exchanged during the decision-making process, focusing on information, action and coordination requests and transfers (in terms of frequency counts and the ratio of transfers to requests) and on the communication check.

Tangible and intangible vulnerabilities affecting the fulfilment of the decision making success indicators are identified and recorded. For the sake of simple data processing and analysis, observed tangible and intangible vulnerabilities are annotated in a matrix. Tables 2 and 3 show examples of how physical and information vulnerability matrices would be filled for an event. As shown in Table 2, the example represents an event in which deployment of human resources (DHR), deployment of physical resources (DPR) and damage asset management (DAM) were observed. For each observed task and/or subtask, comments on observed tangible and intangible vulnerabilities are also recorded. For example, amongst all other vulnerabilities, it is noted that no standardized damage survey form was associated to DAM task (Table 3).

Table 2 – Example of decision making vulnerability matrix for the Physical Domain.

PHYSICAL DOMAIN					
S_{P1} - Minimisation of road closures duration and variability					
Task/Sub-tasks				Tangible Vulnerabilities	Intangible Vulnerabilities
DHR	DPR	TTM	DAM		
☑	☑	-	-	Insufficient Resources	
-	☑	-	-		Lack of Situation Awareness about available resources
-	-	-	☑	No standardised damage survey form	

Table 3 – Example of decision making vulnerability matrix for the Information Domain.

INFORMATION DOMAIN					
S_{I1} - Level of Connectivity					
Task/Sub-tasks				Tangible Vulnerabilities	Intangible Vulnerabilities
INTRA	INTER	MEDIA	PUBLIC		
☑	☑	-	-	-	Poor degree of interactivity
S_{I2} - Information richness					
INTRA	INTER	MEDIA	PUBLIC	Tangible Vulnerabilities	Intangible Vulnerabilities
☑	☑	-	-	Technical problems limiting the information sharing in visual form via voice or multimedia transmissions	-
☑	☑	-	-	Absence of supporting tools like Geographical Information System, or Decision Support System.	-

2.3 QDM performance level

Using the qualitative or quantitative information previously recorded, the overal decision making performance is assesed considering the applicability, the peformance level and the degree of fulfilment of all success indicators for all four domains under analysis. These elements of the QDM peformance assessment are defined as follows:

- **Applicability:** identify whether or not a success indicator is relevant to the specific decision making process under analysis;
- **Performance Level:** report the suitability and quality achieved in performing the different sub-tasks. For each *i-th* sub-task/sub-cognitive element pertinent to a certain *j-th* success indicator within the analysed domain *d*, a performance levels $P_{i,j,d}$ is assigned within a five-level qualitative scale (Excellent = 5; Very Good = 4; Good = 3; Regular = 2; and Poor = 1). A zero score, corresponding to a Non Performed = 0 condition is furthermore considered;
- **Degree of fulfilment:** assess the performance level achieved for each success indicator, based on observed sub-tasks and sub-cognitive elements. Mathematically, the degree of fulfilment $F_{d\,j,}$ is evaluated combining, according to a weighted average, the performance levels $P_{i,j,d}$ attributed to the sub-task/cognitive elements pertinent to the *j-th* success indicator.

$$F_{dj} = \sum_{i=1}^{t} \alpha_i P_{i,j,d} \qquad \text{(Eq. 1)}$$

where α_i is a normalised weight associated to the *i-th* sub-task/cognitive element pertinent to a *j-th* success indicator; referred to as **sub-task/cognitive elements normalised weight**. The normalised weighted average allows accounting for the different proportional relevance that each sub-tasks/cognitive element could have in the fulfilment of a certain success indicators.

- **Decision domain global score:** compute a global score representing the quality of the decision making process pertinent to the specific domain. The decision domain global score D_d is computed combining, according to a normalised weighted average, the degree of fulfilment $F_{j,d}$ evaluated for the success indicators pertinent to the domain D_d according to Equation 2.

$$D_d = \sum_{j=1}^{r} \beta_j F_{j,d} \qquad \text{(Eq. 2)}$$

where β_j is a normalised weight associated to each success indicators *j-th* pertinent to the domain *d* and referred to as **success indicator normalised weight**. The normalised weighted average allows accounting for the different proportional relevance that each success indicator could have in the quality achievement of a certain domain.

Finally, a global score for the decision making quality is measured combining the scores evaluated for the 4 different domains, as follow:

$$DM = \sum_{d=1}^{4} \gamma_d D_d \qquad \text{(Eq. 3)}$$

where γ_d is a normalised weight associated to each domain D_d and referred to as **success indicator normalised weight**. The normalised weighted average allows to account for the different proportional relevance that each domain could have in the global quality of the decision making process. The values of the sub-task normalised weight, α_i are supposed to be defined before the implementation of the QDM analysis liaising with decision-makers. Sub-task weights accounts for issues that can influence the decision making processes such as pre-defined strategies and priorities, expectations from end-user and other responding organisations, resources availability, organisation's role, etc. Multi-criteria analysis approaches can effectively support the process of priority and expectation identification and weighting (Ferreira *et al.*, 2009).

Using the decision domains (D_d) and global score (DM) obtained respectively through Equations 2 and 3, a roading organisation can assess, on one hand its performance relatively to each single domain and on the other hand its performance relatively to the overall decision making process. A five level qualitative scale has been assumed to this aim categorising the performance of the decision making process in terms of: Poor Resilience, Limited Resilience, Regular Resilience, High Resilience and Outstanding Resilience. Table 4 shows the graphical output of the QDM analysis method. Attributes summarising the strengths and weakness affecting the single domain and the overall decision making processes of the organisation, have been identified for each one of the five levels identified (Table 4). According to the assumed scale, the decision making process of an organisation that achieves a global score DM=1.42 is classified at a Limited Resilience Performance Level, which means that the organisation is/has: dysfunctional; limited adaptability, not effective in various circumstances; limited in solutions delivery; and incapable to provide feedback to involved organizations.