ORGANIZATIONAL OPERATIONS PLANNING AND DECISION-MAKING DURING EXTREME EVENTS: THE NEW ZEALAND STATE HIGHWAY ORGANIZATIONS CASE

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ABSTRACT

Operations planning and decision-making research for emergency management have increased in both academia and industry due to catastrophic events that have occurred in the past two decades. Recovery and reconstruction are intrinsically dependent on events' characteristics and how planning, preparation and response are performed. Numerous transportation research have already focused on mathematical optimization, network reliability, risk management, and decision-making. Findings are still to be combined into common frameworks so better understanding of decision-making during emergency events can be achieved by the transportation community. This paper presents an academic approach to analyze extreme event decision-making within roading organizations using data from practical experiences. An emergency exercise observation and game simulation data collection method as well as a data analysis framework are proposed to study extreme event decision-making. A series of case studies were conducted by rigorously observing seven emergency exercises and simulating twelve game-based scenarios at several New Zealand roading organizations. Data collected during such experiences have proven the applicability of the framework, supporting two major findings: i) Extreme event decision-making is dependent on previous planning and experiences, confirming Naturalistic Decision-making models; and ii) Emergency response and recovery can be associated with two time frames (short and long terms objectives).

INTRODUCTION

Natural and man made disasters affect communities on a frequent basis. Consequences range from loss of life to economic disruptions. The International Federation of Red Cross and Red Cross Crescent Societies estimate that the last decade alone accounted for 535,000 deaths and US$ 684 billion in losses from direct damage to infrastructures and crops due to disasters (1).

In spite of great advances in various scientific fields, we still lack information on how people make decisions during crises. Numerous disasters have been comprehensively reported, e.g. the 1994 Northridge Earthquake (USA), the 1995 Kobe Earthquake (Japan), the 2004 Sumatra Earthquake and Tsunami (Asia), and 2005's Hurricane Katrina (USA). However, decision-making factors and management strategies are still poorly described and understood.

Many transport studies have focused on developing systems for emergency management embedded with evacuation models and shortest paths algorithms (2 – 6). There is also extensive literature on network reliability (7), risk management and Information Technology applications (e.g. Geographic Information Systems for mapping, Dynamic Data Bases for information sharing). Such approaches support the estimation of traffic flows, route prioritization, hazards materials transportation, spatial and non spatial data analyses. However, they cannot provide simple guidance and information to facilitate decision-making in the immediate aftermath of extreme events. In this respect, decision-making studies have become popular endeavors in order to fill gaps identified in extreme event decision-making (8, 9).

Lack of information on how decision-makers manage transport networks during stress-laden circumstances impairs a comprehensive understanding of emergency operations planning and decision-making. It is ultimately associated with poor performances or inappropriate responses, creating economic disruptions and loss of life.

An understanding of how decision-making activities occur during crisis may gear organizations and governments towards the development of better infrastructure management processes and response / recovery practices. Hence, transportation research (10 – 12) and decision-making theories (13, 14) have been applied to study emergency management. Regardless of individual approaches, researchers have been trying to collect data sets to analyze decision-making processes during extreme events. A particular research approach is the simulation of complex scenarios to collect comprehensive data and identify new concepts (15, 16).

In New Zealand, emergency exercises have become a popular practice. The rigorous observation and analysis of seven exercises in the country have proven that exercises can emulate complexities observed in real events. Many learning opportunities have arisen from the simulations and vast knowledge acquired as the involved personnel acted as though the situation were real. Finally, the high complexity of decision-making during emergency events, combined with limitations from the observation method, indicated the need to design an additional experiment, in which specific situations could be isolated and analyzed.

This paper proposes a combined observational and simulation approach to collect comprehensive data about organizational decision-making during emergencies. After this introduction, a data collection framework comprising emergency exercise observation and game-based simulations is proposed. Thereafter, a series of case studies are presented, i.e. the observation of seven emergency exercises in New Zealand and simulation of twelve game-based scenarios. Final findings as well as conclusions / future research are respectively presented in the last two sections.

FRAMEWORK FOR OBSERVING AND SIMULATING EMERGENCY EXERCISES

Combining both Emergency Management and Decision-making theories, we propose a data collection and analysis method to understand organizational planning and analyze decision-making during both simulations and real extreme events. Observations of emergency exercises and real events, along with individual simulations, were designed to collect necessary data for this study.

A comprehensive literature review consolidated the fundamental concepts needed to develop the research framework. In this context, an Emergency Event is any happening that causes loss of life, injury, illness, distress thus requires significant co-ordinated response (17). Emergency Management is defined as a four stage process comprising Mitigation, Preparedness, Response and Recovery / Reconstruction (1, 18 - 20). Finally, Decision-making Theories indicated both Naturalistic and Normative Decision Models as the most appropriate models to study decision-making during emergency events (21 – 27).

With this theoretical background, we set up a Data Collection and Analysis Framework, in which emergency exercises are initially observed according to a five step process, described as follows:

1. Search appropriate upcoming emergency exercises in the country;
2. Once an exercise is identified, contact organizations responsible for organizing the exercise in order to check the possibility to take part as observers;
3. If participation is authorised, become familiarized with dynamics, individual participants, objectives, major players, scenario and injects;
4. Arrange / define necessary surveying consumables / processes and conduct the exercise observation focusing on knowledge elicitation and representation as described in Table 1; and
5. Report the experience to fellow researchers to exchange and collect alternative points of view.

TABLE 1 Activities and Expected Outcomes from Real Events and Exercise Observation

<table>
<tr><th colspan="2">Step</th><th>Activities and Expected Outcomes</th></tr>
<tr><td>1</td><td rowspan="2">Knowledge Elicitation</td><td>Observation of decision making process during real and simulated extreme events and tracing of the decision making stories
Qualitative assessment of tangible/intangible vulnerabilities affecting the decision making</td></tr>
<tr><td>2</td><td>Debriefs and in-depth interviews with subject matter experts following real and simulated events. Identification of the cognitive elements that underlie decision making</td></tr>
<tr><td>3</td><td>Analysis and knowledge representation</td><td>Extracting meanings from the acquired data and information and displaying the results</td></tr>
</table>

An assessment framework for decision-making activities performed during crises, simulated by emergency exercises, was defined according to concepts acquired from the literature review. Hence, key elements that play fundamental roles during decision processes were defined as information sharing, decision makers' expertise and experience and individual and shared situation awareness.

We further identified the Defence Command and Control Research Program (CCRP), popularly used in the USA for professional military training, to group the abovementioned elements into four decision-making domains: physical, information, cognitive and social (28). Thus, decision-making command and control operations were individually specified and adapted for our particular research by identifying a set of non-exhaustive tasks and sub-tasks for each decision domain as follows:

- **Physical Domain**: Response Actions – Deployment of Human Resources, Deployment of Physical Resources, Temporary Traffic Management and Damage Assessment and Management;
- **Information Domain**: Data Processing – Data collection, Data analysis / storing / summarising, Data sharing / disseminating and Data maintaining / updating; Communication – Communication intra-organizations, Communication inter-organizations, Communication with media and Communication with public;
- **Cognitive Domain**: Situation Awareness – Perception of the evolving scenario, Understanding of needs and Projection of future; and
- **Social Domain**: Collaboration and Coordination – Collaboration intra-organizations.

Each sub-task refers to specific activities performed by roading organizations, which ultimately contributes to set up robust and integrated management practices. For instance, inter and intra-organizational communication processes are established so information loss can be reduced. Positive information sharing contributes to better data collection. The analyses of available data under human cognitive and organization's social domain support decisions on the physical level such as deployment of resources to specific locations, implementation of traffic management routines.

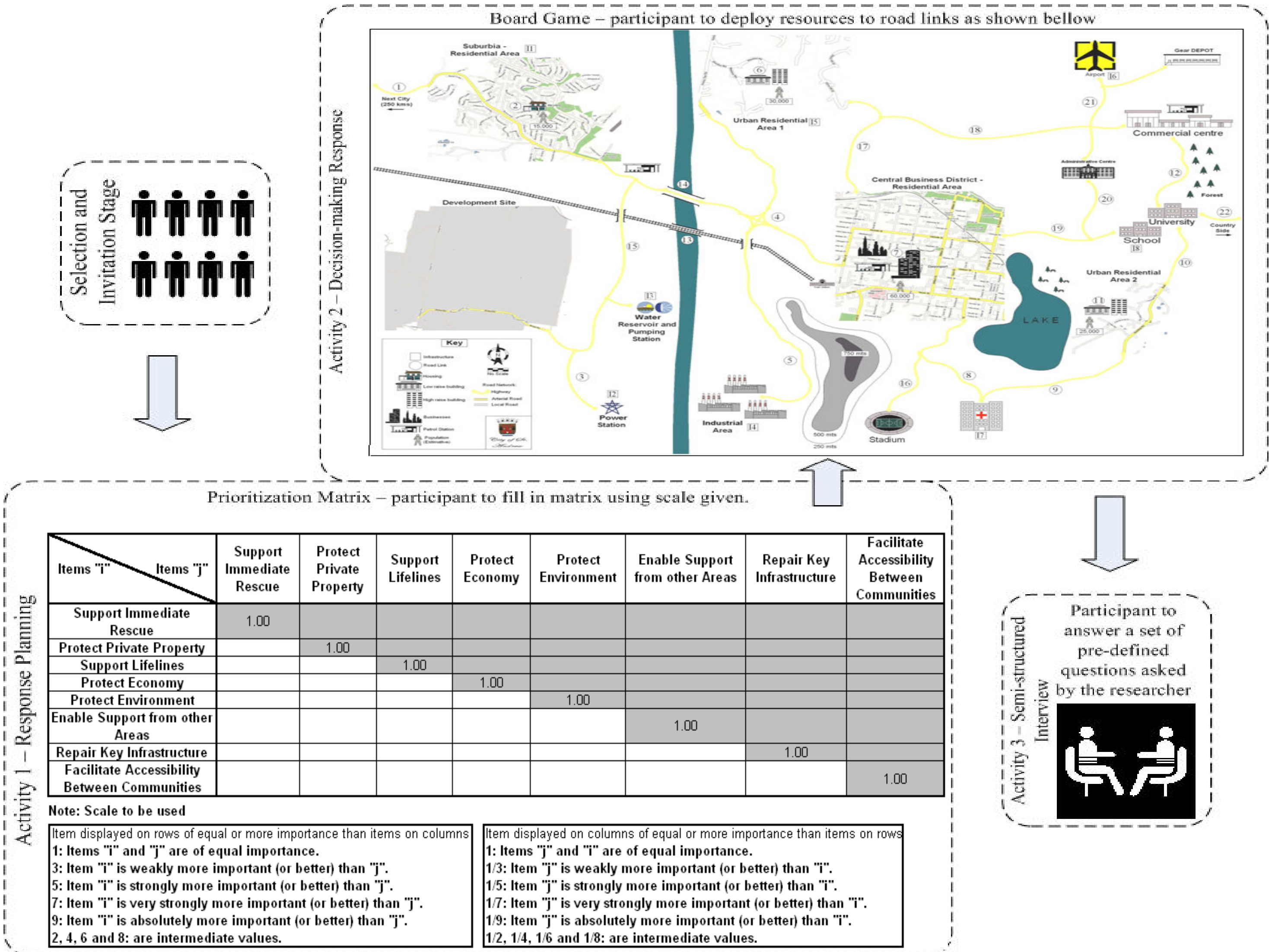
The identification of decision-making sub-tasks along with general information collected during the observations supported the assignment of successful indicators for each domain. Successful indicators refer to main objectives intended to be accomplished when road organizations are operating under crises.

- **Physical Domain**: Minimization of road closure duration and variability, Maximization of accessibility to strategic services and places, and Minimization of response and recovery costs;
- **Information Domain**: High degree of connectivity, Information richness, and Extent of information reach;
- **Cognitive Domain**: Individual situation awareness, Level of training and experience, and Good leadership and unit cohesion; and
- **Social Domain**: Responsiveness to the needs of emergency management agencies, Technical advise to leading emergency management agencies and lifeline groups, and Coordination of actions with all involved agencies.

Complimentarily to the observation method, a game-based scenario simulation was developed aiming at analyzing specific aspects about the physical domain. Similar techniques to those used in emergency exercises, i.e. an evolving dynamic scenario, were considered in order to develop the game-based approach. The experience was designed to be conducted with a sole participant so a controlled research environment could be created and specific data about decision-making could be collected. For this purpose, two main tools were designed (namely, Prioritization Matrix and Board Game) to support analyses aiming at the identification of response patterns. The combined observation and simulation framework intends to overcome intrinsic limitations from individual approaches in order to support comprehensive analyses of organizational planning and decision-making during extreme events.

At operational levels, the game simulation is conducted by inviting and running the emergency scenario with practitioners and academics. Figure 1 presents the two tools abovementioned. The case studies are conducted by firstly asking participants to fill in the Importance Matrix as illustrated. The matrix is based upon a multi-criteria process, which provides data to estimate the importance of each response objective. This technique also allows the data analyst to identify illogical weight assignment and avoid the use of poor quality data. Subsequently, the game simulation takes place by simulating an emergency scenario for a hypothetical city. Participants receive injects (or scenario information) every seven minutes, which represents a full response day, and are required to deploy available resources to damaged assets. Immediately after each resources deployment, the game controller asks the participant to state the main motivations for his/her decisions. A final semi-structured interview is conducted in the end of the simulation in order to collect general qualitative data. Full specifications on both game and scenario development can be found in Ferreira *et al.* (29). Note that Figure 1 only intends to provide a simple illustration of the board game as a better resolution picture is presented in the reference above.

The data analysis process focuses on scrutinizing individual resource deployment along with declared priorities and road transportation network characteristics. Qualitative data from interviews are used to fill possible existing gaps created by missing data.



Items "i" \ Items "j"	Support Immediate Rescue	Protect Private Property	Support Lifelines	Protect Economy	Protect Environment	Enable Support from other Areas	Repair Key Infrastructure	Facilitate Accessibility Between Communities
Support Immediate Rescue	1.00							
Protect Private Property		1.00						
Support Lifelines			1.00					
Protect Economy				1.00				
Protect Environment					1.00			
Enable Support from other Areas						1.00		
Repair Key Infrastructure							1.00	
Facilitate Accessibility Between Communities								1.00

Note: Scale to be used

Item displayed on rows of equal or more importance than items on columns
1: Items "i" and "j" are of equal importance.
3: Item "i" is weakly more important (or better) than "j".
5: Item "i" is strongly more important (or better) than "j".
7: Item "i" is very strongly more important (or better) than "j".
9: Item "i" is absolutely more important (or better) than "j".
2, 4, 6 and 8: are intermediate values.

Item displayed on columns of equal or more importance than items on rows
1: Items "j" and "i" are of equal importance.
1/3: Item "j" is weakly more important (or better) than "i".
1/5: Item "j" is strongly more important (or better) than "i".
1/7: Item "j" is very strongly more important (or better) than "i".
1/9: Item "j" is absolutely more important (or better) than "i".
1/2, 1/4, 1/6 and 1/8: are intermediate values.

FIGURE 1 Game-based Scenario Simulation Operationalization

EXERCISE OBSERVATION AND GAME SIMULATION CASE STUDIES

Seven emergency exercises throughout New Zealand were observed according to the five step process described in the previous section. Dates, locations and details are presented in Table 2. The experiences comprise five earthquake events, one weather related disaster and one volcano eruption. Although earthquake simulations were the majority, complete experiences were acquired as weather and volcanic exercises were also observed.

The observation of exercises has provided a great deal of information about organizational operations. Group settings, promoted by exercise simulations, contributed to better understand the dynamics associated with extreme event decision-making. For instance, it was noticed that organizational structures such as Coordinated Incident Management System (CIMS) are implemented in order to reduce communication disruptions, information loss, processes optimization, situation analyses. Observations also indicated that decision-making is heavily dependent on individual hierarchy within organizations and experience.

However, it has been found that collected data collected is potentially biased as exercises were diverse in nature (i.e. introductory, complex, local, regional, national and international) and participants had different backgrounds.

In spite to solid decision-making performances at most exercises, remarkable deficiencies associated with Physical, Information and Cognitive Domains can be described as follows:

- **Physical Domain**: insufficiency and/or difficulties in deploying human and physical resources;
- **Information Domain**: lack of alternatives ways of communications and lack of dedicated personnel to collect process and share information. Impossibility for all the decision makers to have access to intra-organization information; and
- **Cognitive Domain**: lack of individual situation awareness combined with deficiencies in decision makers' training and experience.

Particularly for the Physical Domain, Dantas *et al.* (30) scrutinize shortcomings as well as propose a series of actions towards the improvement of resource deployment and decision-making optimization.

Complimentarily, twelve game simulations were conducted in order to fill research gaps identified in the observation method. Initially aimed at a vast comprehension of human cognitive decision-making processes, the game simulation has proven to be very efficient in analyzing the Physical Domain. In this context, resource deployment data and decision-making motivations were examined leading to a new series of findings as follows.

TABLE 2 Observed Emergency Exercises in New Zealand

Name Date Location	Simulated event	Exercise Typology	Aim	Observed Organizations
Capital Quake 14th / 15th November 2006 Wellington	Major earthquake in Wellington	National civil defence functional exercise organized by the MCDEM	Test New Zealand's all-of-nation arrangements for responding a major disaster	Transport Agency Regional Office, Wellington
Marconi Exercise 8th June 2007 Auckland	Tropical cyclone causing significant damage and flooding in Auckland	Distributed tabletop exercise organized by the Auckland Engineering Lifelines Group	Lifeline utility co-ordination processes in the Group EOC with focus to info transfer	Transport Agency Traffic Management Center, Auckland
Pandora Exercise 14th and 15th September 2007 Christchurch	Major earthquake in Whataroa	Regional functional exercise involving all South Island CDEM Groups and the National Crisis Management Centre (NCMC)	To practice and evaluate regional CDEM Groups operational procedures	Regional and City Councils
United Nations Training Exercise (UNDAC) 25th October 2007 Christchurch	Major earthquake in Christchurch	Asia Pacific United Nations Disaster Assessment and Coordination (UNDAC) Introduction Course	UN co-ordinated, international response to support Local Emergency Management Agencies.	International Aid Organization (Christchurch based team)
Icarus Exercise 22nd November 2007 Wellington	Major earthquake in Wellington	Functional exercise part of the Transit NZ scheduled annual training	Train staff in their roles within EOC (Emergency Operations Centre); priorities allocation and communication between organizations; test aerial reconnaissance arrangements between Transport Agency and Regional Council.	Transport Agency Regional Office, Consultants, Contractors and Regional Council
Icarus II Exercise 14th May 2008 Wellington				
Ruamouko Exercise 13th March 2008 Auckland	Volcano eruption in Auckland	Tier 4 national-level functional exercise in accordance with the Ministry of Civil Defence and Emergency Management National Exercise Program	Test all-of-nation arrangements to respond a major disaster with particular focus to roles, responsibilities, arrangements and connections between, local, regional, national and international agencies	Transport Agency National Office, Emergency Operations Centers (Wellington, Auckland and Waitakere) and Transport Agency Traffic Management Center (Auckland)

Game simulations were conducted over a 3-month period. Twelve case studies were performed with local, regional and national roading authorities, consultants and contractors.

Data collected were initially considered suitable for the study due to participants' conduct. It was organized into two sets: qualitative and quantitative. Qualitative data included audio records from interviews conducted at the end of each game simulation and quantitative data response objectives prioritization and number of resources deployed to each road link during the simulation.

After processing the data, Response Planning and Decision-making Response were respectively analysed. Planning refers to cognitively structuring response prior to the simulation. Additionally, Decision-making Response is the actual response process, limited in the proposed game-based simulation to the deployment of resources to each road link according to experienced damage.

Decision planning was initially analyzed using data collected by the Prioritization Matrix presented in Figure 1. Response priorities were calculated for the eight objectives using Equation 1. Results were plotted in a Box Plot Diagram as well as individual priorities (Figure 2). The visual analysis of the Box Plot Diagram indicated a series of possible outliers (observations that are numerically distant from a pattern or cluster of data). Those values were then excluded from the data set and median values for priorities were finally estimated as presented in Table 3. Finally, three levels of priority were assigned to each Response Objective according to priorities distribution.

$$P(RO_i) = \frac{\sum_{j=1}^{n}\left(w_{ij} \Big/ \sum_{i=1}^{n} w_{ij}\right)}{n} \text{ ; given } 1 \le i \le 8 \qquad (1)$$

Where: $P(RO_i)$ – priority estimated for the i^{th} response objective

i – row items

j – column items

n – number of row items or column items

w_{ij} – importance or weights assigned by participant

TABLE 3 Final Median Values for Response Priorities

Priority Level	Response Objective	Response Priority
High	Support Immediate Rescue	33.00 %
	Enable Support from other Areas	17.00 %
Medium	Support Lifelines	15.00 %
	Repair Key Infrastructure	14.00 %
Low	Facilitate Accessibility Between Communities	7.00 %
	Protect Environment	6.00 %
	Protect Private Property	4.00 %
	Protect Economy	4.00 %

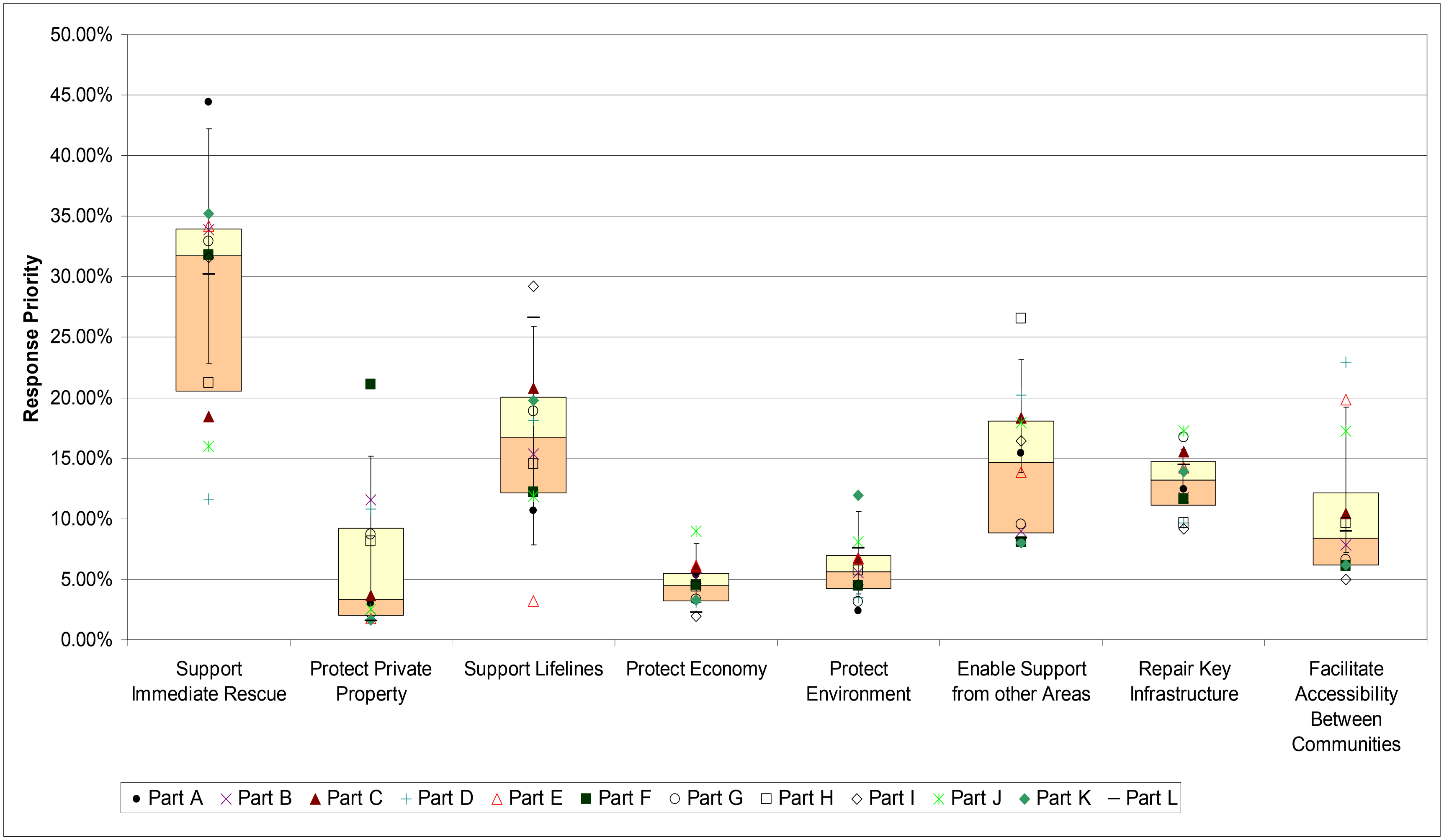


FIGURE 2 Priority's Box Plot Diagram and Participants' Outliers

Decision-making Response was analysed according to the number of resources deployed to each link of the road network during the simulation. Each unit of resource is considered to contribute towards eight response objectives presented in Table 2. Equation 2 was used to calculate Contributing Resources (CR) according to a weighting system proposed for the game simulation. It considers the proportion of "response services" that individual links can support during the response process. For instance, resources deployed to road link "*n*" contributes 70% to "Support Immediate Rescue", 20% to "Enable Support for Other Areas" and 10% to "Support Lifelines".

$$CR_l = \sum_{r=1}^{n} (R_r \cdot W_l) \qquad (2)$$

Where: CR_l – Contributing Resources for the l^{th} link
W_l – Weighting System for the l^{th} value
R_r – Total number of resources deployed to r^{th} road link
l – response objectives ($1 \leq l \leq 8$)
r – road links plus airport ($1 \leq r \leq 15$)

Percentual CR_i results were plotted as shown in Figure 3, which points out to two major findings. Firstly, resources deployment aligns with Response Planning as participants ultimately aim at fulfilling planning strategies defined prior to the simulation (i.e. priorities given in the Importance Matrix). We could also observe Naturalistic Decision-making tendencies in emergency management. Although participants did not have access to the weighting system and were not familiar with the scenario, they have used previous general experiences and expertise to guide / justify their decisions. This was confirmed during final interviews, when participants declared that potential benefits from different resource deployment strategies were assessed according to response priorities and personal experiences / expertise so the "most appropriate" response could be identified and implemented.

Finally, a temporal data analysis has indicated two time frames. On one hand, participants aimed at "Support Immediate Rescue" and "Enable Support from Other Areas". Those two objectives are dependent on an effective and short time responses so lives can be saved by rescuing people and offering appropriate treatment. An urgency in response is reported by rules such as the "Golden Hour" and the "Golden Ten Minutes" (31). On the other hand, medium term response refers to "Support Lifelines" and "Repair Key Infrastructure" due to contingency plans, i.e. resources would still be available for some time to affected regions although at limited levels. This time frame provides the "necessary gap" to finalise rescuing operations and re-mobilize resources for medium term response. Finally, economic recovery and environment and private property protection are mainly associated to recovery / reconstruction. This phase is usually identified by human life not been endangered any more as well as affected communities being able to experience liveable standards (e.g. economic trading, businesses, services supply, tourism).

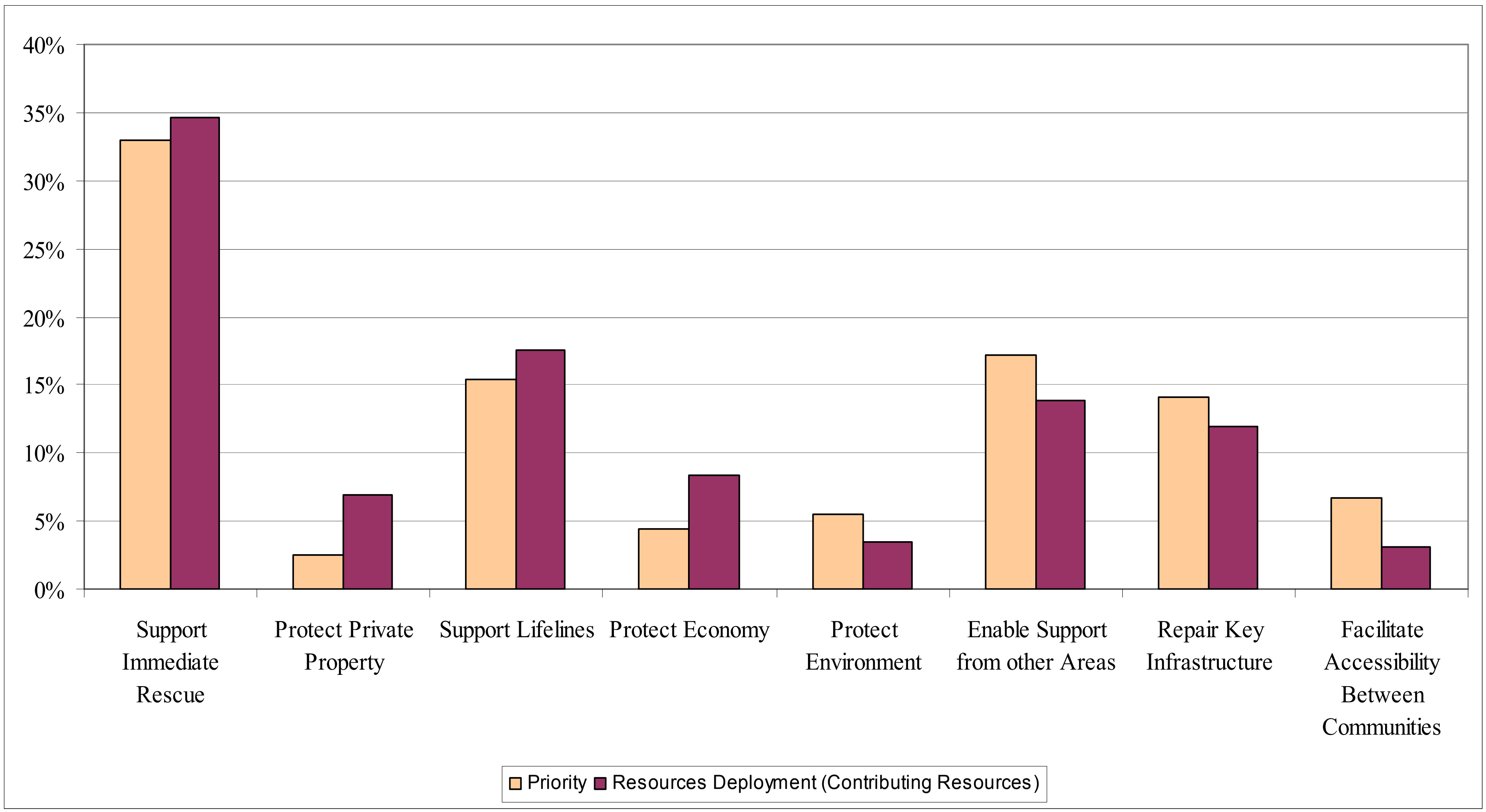


FIGURE 3 Response Planning and Resource Deployment

FINDINGS

Some authors define decision-making as a series of actions that bring changes to the environment or management processes. This research indicates that organizational extreme events decision-making is a function of response planning and events' unfold. Information generated from exercise observations activities and game simulations can be summarized into two findings as follows:

- Response planning matches decision-making (i.e. resources deployment). Response priorities estimated from Importance Matrices are considered during the simulation as resource deployment aim at fulfilling objectives accordingly to their respective importances. This fact confirms the rational decision-making process presented in the scientific literature by Naturalistic Decision Model, in which expertise / experience, knowledge / memory and improvisation play key roles;
- Short and long term response patterns are figurative references to emergency management response and recovery activities. Data collected have proven that response efforts focus on immediate needs such as "Immediate Rescue" and "Enable Support from Other Areas", while recovery broadens emergency management into longer time frames, resources scattering and building up efforts towards long term demanding goals.

CONCLUSIONS AND FUTURE RESEARCH

This paper presented a new method to collect data and analyze organizational operations and decision-making during extreme events. Based on Decision-making and Emergency Management theories, an observation and simulation framework was conceptualized for the specific case of roading organizations. The method has shown to be capable to evaluate both general management operations and specific decision-making processes in order to identify response patterns.

The observation of emergency exercises supported the identification of tasks and sub-tasks for four decision-making domains commonly considered in the literature (i.e. physical, information, cognitive and social). Each domain was further associated with response objectives or successful indicators. Although general information could be generated from exercises observations, specific decision-making processes were still unclear. Therefore, specific knowledge was lacking to continue the research.

A game-based scenario simulation tool was developed in order to consider exercises observations' limitations. The game simulation gathered comprehensive data about extreme events decision-making influencing factors. In this context, Response Planning and Decision-making Response were found to be two key processes performed when managing emergencies.

Response planning accounts for prioritization processing and the former for actual resource mobilization and deployment (both physical and human). Experiences supported us to define Extreme Events Decision-making as a Naturalistic Decision-making process, in which situation recognition, pattern matching to memory structures and prototypical situations play vital roles (17, 42). Finally, it was found a temporal pattern in response: i) short term and ii) long term. The "Support Immediate Rescue) and "Enable Support from Other Areas" were identified as short term objectives. The reaming six response priorities were classified as long term objectives with infrastructure repair and lifeline support being flexibly arranged according to specific event's circumstances. For instance, resources were immediately deployed to the industrial area and the main bridge as soon as those places were near "collapse points" with dramatic consequences to the community (e.g. water contamination, loss of major highway link). These actions also re-affirmed the Naturalistic Process as well as highlighted decision makers' improvisation skills.

Finally, future research should target the development and test of decision support tools for roading organizations. We currently envisage a dynamic system collecting real time data to process recommendations to transport managers so decision-making can be facilitated, response times reduced, resources deployment optimized and information better shared among organizations.

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