Dynamic Response Recovery Tool for Emergency Response within State Highway Organisations in New Zealand

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ABSTRACT

Abstract of a thesis submitted in partial fulfilment of the
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by Frederico Ferreira

This thesis reports the research efforts conducted in order to develop the Dynamic Response Recovery Tool. The DRRT was developed as a decision support tool under a holistic approach considering both emergency management research and transportation studies. The proposed system was assessed by a series of case studies in order to identify its efficiency and suitability for roading organisations.

Knowledge developed from two novel research approaches are comprehensively described throughout the thesis. Initially, we report on the observation of three emergency exercises and two real events in New Zealand. This set of activities indicated the complex and dynamic environment in which emergency management takes place as well as organisational settings and management structures implemented to better respond and recover from disasters events. Additionally, a secondary approach was designed to overcome limitations identified in the observation method. In this context, a game-based scenario simulation was developed and conducted with twelve participants. With a focus in resource deployment decisions during emergencies, the game simulated an earthquake scenario in which participants had to allocate physical resources to fix damage created in a road network. Simulations indicated that Naturalistic Decision-making processes were used to respond to the scenario. Thus, resource allocation followed planning priorities defined previously the simulation, which further considered individual experiences and knowledge.

Taking advantage from the findings achieved and knowledge developed by the observations and game simulations, the DRRT was designed using the conceptual background identified in the literature review. The DRRT was conceptualised as a logistics sub-system as part of the broad field of Disaster Management. In particular, the DRRT was geared towards supporting decision-making by providing procedural recommendations and identifying optimum physical deployment strategies. In order to assess the proposed system, an Information Technology application was built according to the DRRT's specifications.

A series of eleven individual and three group simulations was performed in order to assess the DRRT. Data collected through the application indicated that the DRRT enhanced decision-making during extreme events. In specific, case study participants using the system at greater levels achieved better decision-making accuracy than those disregarding completely or partially the system. Case studies also indicated that emergency management knowledge was represented by the application and its logistics model provided participants with vital information to optimise resource allocation.

Keywords: Disaster Management, Emergency Response, Transportation, Roading Organisations, Information Technology, Decision Support System and Expert System.

RESUMO

Resumo de tese submetida como requerimento
parcial para a obtenção do título de Doutor

Sistema Dinâmico para Resposta a Situações de Emergência em Organizações Rodoviárias na Nova Zelândia

por Frederico Ferreira

Essa tese apresenta as atividades de pesquisa conduzidas para a proposta e desenvolvimento de um sistema dinâmico para resposta em situações de emergências. Nomeado DRRT (*Dynamic Response Recovery Tool*), o sistema foi desenvolvido segundo premissas básicas de ferramentas de apoio à decisão e uma análise holística das teorias de gerênciamento de emergências e estudos em transportes. Uma série de estudos de caso foi finalmente conduzida de forma a se identificar efficiência e limitações do sistema proposto.

Uma vasta gama de experiências e conhecimento gerado através de dois metódos de pesquisa inovativos são descritos no decorrer da tese. Inicialmente, a observação de três simulações de emergências e dois eventos ocorridos na Nova Zelândia são apresentados. Tais atividades subsidiaram análises do complexo e dinâmico ambiente no qual o gerênciamento de emergências ocorre bem como sistemas organizacionais implementados para subsidiar a tomada de decisão. Complementarmente, a simulação de emergências usando-se de conceitos de jogos foi proposta de forma a superar limitações de pesquisa e coleta de dados identificadas no decorrer das atividades de observação. Focando-se em atividades de alocação de recursos durante a resposta em emergências, o método foi conduzido com 12 participantes. Tais experiências subsidiaram a coleta de dados e a identificação de processos naturalísticos de tomada de decisão. Nesse sentido, concluiu-se que a alocação de recursos segue prioridades previamente definidas pelo decisor, as quais são influenciadas por conhecimento e experiências pessoais.

Utilizando-se do conhecimento gerado através dos metóds de pesquisa descritos no parágrafo anterior, o DRRT foi conceptualizado como um sub-sistema logístico contido no amplo campo de conhecimento da gerência de desastres. Em específico, o DRRT objetiva o apoio à decisão através do fomento de recomendações no âmbito de processos e identificação de estratégias ótimas de alocação de recursos físicos na rede de transportes.

Uma série de onze estudo de casos e três simulações em grupo foi conduzida para a avaliação da eficácia do sistema proposto. Conclui-se então que o DRRT contribui para o aumento da performance de processos de decisão em situações de emergências. Em específico, participantes que utilizaram o sistema de forma mais consistente obtiveram melhores performances quando comparados com participantes que não utilizaram o sistema em sua total capacidade. Dados coletados também indicaram que o modelo de alocação de recursos proposto no sistema fomentou identificação de estratégias ótimas para o reparo da rede de transportes em função dos danos sofridos e disponibilidade de recursos.

Palavras-chave: Gerênciamento de Desastres, Resposta à Emergências, Transportes, Organizações Rodoviárias, Tecnologia da Informação, Sistemas de Apoio à Decisão.

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1 INTRODUCTION

This research investigated the decision-making process during emergency events at New Zealand State Highway Organisations (SHO[1]). These organisations face conflicting priorities and resource limitations during emergency response and recovery activities. Throughout this research, these issues were examined, in order to develop an understanding of their genesis. This understanding then enabled us to propose a new conceptual tool that may help SHO in responding to and recovering from emergency events.

Recent disasters around the world and in New Zealand (NZ) have highlighted the limitations of the concepts and tools currently available to facilitate emergency management. On one hand, products that are developed based purely on the information gained from practical experiences (e.g. response manuals) sometimes do not allow the understanding of the complex nature of emergencies so it can jeopardise quick and effective decision-making. On the other hand, academic/technical endeavours and information technology systems and tools usually require too much data and too many resources to be effectively and consistently applied during real events.

These issues have helped to identify a gap between science and practice. In order to shrink this gap, decision support concepts from Decision Support Systems (DSS) and Expert Systems (ES) were employed (along with the expertise gained from practical experiences in simulated emergency exercises and games) to design and implement a conceptual system known as the Dynamic Response Recovery Tool (DRRT). Finally, a series of case studies with New Zealand's organisations were conducted in order to assess the DRRT's efficiency and suitability for SHO.

The first section of this chapter contains a brief overview of Emergency Management Research. The subsequent sections are dedicated to the research motivation, the scientific problem/thesis objectives definition and the research method explanation. The last two sections discuss the

[1] SHO comprise New Zealand Transport Agency (NZTA) and its regional contractors and consultants.

challenges and areas of contribution that could be made based on this research, as well as a description of the thesis structure.

1.1 The History of Disasters and Emergency Management Research

Some affirm that disasters occurred in human history since its origin. For instance, the floodings events associated with the biblical story of Noah's Ark is claimed by many as been accurately and reliably described in the Bible. Despite arguments and myths, disasters were first recorded in human history according to currently scientific standards in 430 B.C., when Athens (Greece) experienced the catastrophic effects of a typhus epidemic. While the information available is at times both controversial and imprecise, disasters (either natural or man-made) have been cyclically harming societies throughout recorded history. Scaruffi (2008) reports a very extensive list of the worst disasters experienced by humanity. This list comprises more than 200 events, extending from 430 B.C. to 2008, and includes disasters such as famines (Japan, 1181), volcanic eruptions (Italy, 1631), yellow fever (Cuba, 1648), plagues (Russia, 1654), cholera (Russia, 1830), cyclones (India, 1864), smallpox (France and Germany, 1870), typhoons (China, 1881), influenza pandemics (worldwide, 1957), river floods (Vietnam, 1971), sea floods (Bangladesh, 1970), heat waves (USA, 1995), earthquakes (Japan, 1995), meningitis (West Africa, 1996), tsunamis (Asia, 2004) and hurricanes (USA, 2005).

Modern society acknowledges that many disasters are both hard to manage and very difficult to predict (e.g. earthquakes and tsunamis). Nevertheless, when they can be and are better managed, the associated consequences are reduced. Earthquakes and floods cannot be stopped, but people employed across many fields (e.g. engineering, management, policy making and community support) can act in decisive ways that ultimately reduce a disaster's potential social and economic impact.

According to the International Federation of Red Cross and Red Crescent Societies (IFRCRCS) (2002), disasters accounted for 535,000 deaths and US$684 billion in losses from direct damage to infrastructures and crops in the decade preceding 2001 alone. Jain and McLean (2003) conclude that disaster responses are characterised by a series of interdependent events that struggle to coexist amidst conflicting priorities, random resource needs (human and physical) and uncertain information. These findings have prompted both public and private organisations to seek a better understanding of the issues involved. Public organisations tend to focus their efforts at the community level, in developing awareness, preparedness, risk reduction programmes, response planning and trying to guarantee peoples' well-being during disasters. Private organisations, however, aim at providing services according to community expectations – they ensure their respective businesses' continuity and make the protection of property and staff a priority during emergency events.

Recently, emergency management practices and the related research have together played a significant role in reducing the social and economic impacts associated with disasters. Applications range from operational responses to strategic recovery planning, and involve a variety of organisations. For instance, a well structured emergency management plan includes logistics operations (to effectively deploy resources), public information (to keep the affected public updated), information sharing procedures (to avoid data loss), and strategic reconstruction planning (to ensure long-term recovery). Emergency management is a well structured field that includes worldwide and locally-based organisations, as well as professionals with recognised credentials that can act effectively in a wide variety of situations.

Nevertheless, recent emergency events still show that current emergency management techniques need to evolve further in order to be able to consistently deal with the complex problems that are created by the interface between disasters and the copious amounts of interdependent physical infrastructures that exist. Hurricane Katrina in 2005 and the 2004 Sumatran earthquake and tsunami both offer many insights into limited response and recovery. They ultimately highlight the need to develop and improve the currently accepted emergency management principles and techniques. Cooperation between academia and industry has been fundamental in developing a creative environment that can act as fertile soil for new concepts and the design of up-to-date and user friendly tools for emergency management. In this environment, policies can be created to set up arrangements for pre/post disaster situations; decision-making models are used to understand how response actions are planned and implemented; information technologies can be tested during emergency simulations, and so on. We have identified a research opportunity within this context, and this is detailed in the next section.

1.2 Research Motivation

Natural and man-made disasters are always associated with a series of negative consequences. As presented by IFRCRCS (2002), they primarily cause deaths, chaos and political/economic disruptions. Hurricane Katrina in 2005 accounted for economic losses of approximately US$96 billion (The White House, 2006), while the 2004 Sumatran earthquake and tsunami caused nearly 250,000 deaths (Earth and Space Sciences, 2008) and the September 11 attacks in the United States of America considerably changed international policies on immigration, diplomacy and terrorism threat management.

The backdrop of these recent historical events highlights the need to consistently address a subject that has been progressively labelled by academia, industry and public organisations as "Emergency Management". Emergency Management (EM) is structured in such a way that the risks involved are understood and responses are planned and implemented so that the ultimate impact associated with a disaster is reduced. However, recent events have revealed the limitations of many of the Emergency Management models currently used. One of these limitations is in the area of decision-making (DM). Many studies and products specifically designed for emergency management lack a thorough understanding of DM. Systems that incorporate evacuation models and shortest path algorithms (see examples from Cherrie and Dickson, 2006; Fu *et al.*, 2006; Liu, 1997; Liu et *al.*, 2006a; Liu *et al.*, 2006b; Takeuchi and Kondo, 2003) are all limited in their own individual ways in real situations. Additionally, McManus (2008) highlights that time shortages and the immediate consequences of a vast range of decisions make it imperative to quickly and effectively respond to events in order to reduce disruptions. Data unavailability, inconsistent information, pressure/stress, inoperative systems, and power shortages all end up limiting many of these studies, as they do not offer alternative approaches.

A scientifically structured approach that focuses on end users and decision-making concepts is one way to develop novel concepts, knowledge and tools for emergency management. Engaging with end-users during the development stages is considered vital so as to understand the practical needs and reasoning applied during an emergency response. The scientific method should provide an additional way to meet specific needs according to the existing models, techniques and technologies. Therefore, a combined academic/practical approach can help foment knowledge development and tool designs that will fulfil the specific needs of the end-users, making sure to take into consideration the complex and dynamic nature of emergency events.

Additionally, the literature indicates that roading networks are extremely important during emergencies, but also that there is a lack of studies based around this particular cluster of organisations (which is pertinent to this research). The Auckland Engineering Lifelines (AELG, 2005) states that many organisations depend on road transport to conduct their aid activities during response and recovery. However, few authors have studied decision-making specifically according to end-users' needs and the complex issues the roading sector faces during emergencies. Therefore, the techniques, models and tools used to understand the roading sector have had limited performance levels.

Finally, New Zealand's SHO were chosen as the specific case study for this research, because several disasters (e.g. Canterbury Snowstorm – 2006, Matata/Tauranga flooding – 2005, Manawatu Floods – 2004, Bay of Plenty Earthquake – 1987) have impacted the country in recent years and have badly affected the roading system. These events have ultimately generated large economic losses due to the limited road accessibility and lack of alternative transportation choices[2]. Finally, roading organisations as a group have also been a subject under investigation by the Resilient Organisations Research Programme (ResOrgs, 2008) since 2004.

1.3 Scientific Problem and Thesis Objectives

Some emergency events allow for a warning system, while others do not. Earthquakes can happen at any time for instance, while hurricanes and volcanic eruptions can be predicted in advance. Either way, responding organisations start to collect information as soon as the event happens or is forecasted. Organisations also begin to assess how reliable and complete their collected information is, in order to strategise their response. Specific circumstances and internal information (e.g. resources available, formal obligations, previous arrangements) are used to plan the response actions. This is a typical decision-making process, which involves a complex combination of knowledge, priorities, previous experiences, and resource availability. Following this cognitive and practical exercise, actions are taken and the outcomes of these are further observed/assessed so that response strategies can be changed accordingly.

This dynamic is the one experienced by SHO in New Zealand. The New Zealand Transport Agency (NZTA), together with its consultants and contractors, have to respond to a number of emergencies every year in order to provide an integrated, safe, responsive, and sustainable land transport system (Transit NZ, 2007a). In this context, we address the following scientific problem in this thesis: **How to study New Zealand's State Highway Organisations' decision-making during emergency events subject to changing conditions, multiple actors and various levels of information reliability and availability?**

From the scientific problem stated above, we defined the main objective for this research as the conceptualisation of the DRRT for New Zealand SHO. The DRRT aims supporting decision-

[2] For specific details on recent New Zealand's disasters please refer to GNS Science & NIWA (2006), Newlands (2006), Dantas *et al.* (2005) and Flood Recovery (2007)

making, which can potentially mitigate the impacts of disasters by minimising response times and facilitating the planning and deployment of physical and human resources to conduct repairs. It is argued that well informed, integrated and timely decisions “can save lives, reduce damage and disruption, and enable faster recovery” (GNS Science and NIWA, 2006). Finally, an application of the DRRT’s concepts was implemented and assessed in a case study conducted with NZTA and its associates.

In order to tackle the scientific problem stated above and achieve the main objective stipulated, we divided the focus of this research into six specific objectives:

1. To identify the theories, techniques and knowledge needed to conceptualise the DRRT;
2. To create a data collection framework to be applied within SHO’s decision-making process during emergency events, exercises and simulations;
3. To analyse collected data in order to identify the key factors affecting SHO’s decision-making processes;
4. To develop a decision-making model for SHO;
5. To develop a DRRT application to run case studies; and
6. To assess the efficiency and suitability of the DRRT through a series of case studies.

1.4 Research Method

The research method was designed focusing at a comprehensive study of decision-making during extreme events, so that the DRRT highly regarded proposed, designed and assessed. The conceptualisation of the DRRT focused on the specific end users’ needs and the decision-making concepts identified according to an extensive set of experiences acquired during the research. A final set of case studies was used to assess DRRT’s efficiency and suitability in the context of SHO’s emergency management systems. Figure 1-1 illustrates the proposed research method, which is described as follows.

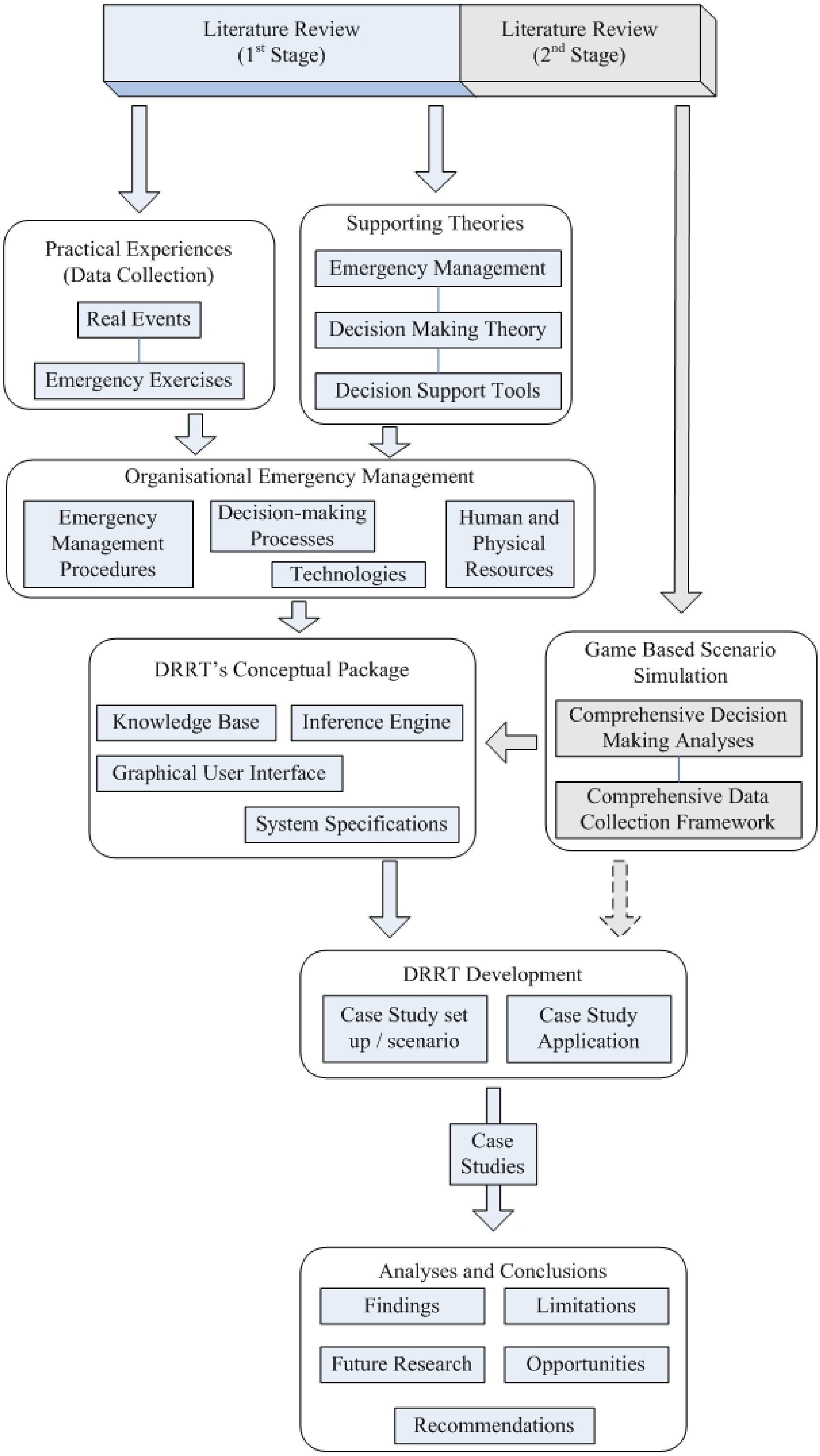

Figure 1-1: Research Method.

The initial literature review for this research comprehensively covered three major topics: Emergency Management, Decision-making Theories, and Decision Support Tools. These supporting theories, along with a number of practical experiences, were originally thought to be sufficient for the development of the DRRT conceptual package.

A series of emergency exercises and real events observations were conducted since 2007. They allowed us to collect and analyse data towards the understanding of organisational emergency management. Thus, a complete analysis process was proposed and it supported the identification of general knowledge regarding organisational decision-making during disasters. Nonetheless, it was found that data gleaned through the observation of emergency exercises and real events and findings from the analysis method had limited applicability to the DRRT development. In this context, the synergy between the supporting theories (i.e. Emergency Management, Decision-making Theory and Decision Support Tools) and the data collected was not possible when only using traditional observational techniques (e.g. naturalistic observation) of real and simulated emergency events.

Therefore, a complementary research approach was planned in order to cope with the possible limitations created by solely observing exercises and real events. A secondary literature review in gaming techniques was conducted, and this indicated that it was possible to collect additional data within controlled environments and experiments. A game-based scenario simulation was then developed in order to support specific data collection in regards to decision-making about physical resource deployment. An earthquake scenario simulation was designed in a hypothetical city, aimed at emulating an emergency environment – complete with the common dilemmas faced in real events such as resource limitations, time pressures and conflicting priorities.

In this backdrop, a comprehensive set of data was collected through the observation of real events/emergency exercises and game simulations. The analysis of this data set, along with the findings from the scientific literature, contributed to our understanding of roading organisations' decision-making in the context of extreme events. Hence, data and knowledge from the activities described previously were used to conceptually design and implement a DRRT application (i.e. partially operational system). The conceptual package included a specification of the knowledge base, an inference engine, a graphical user interface and the semi-operational system to run case studies. The application presented an emergency scenario environment that allowed the user to operate various system's functions in order to experience how the DRRT could be operated during real events.

Case studies were conducted using the DRRT application to support the assessment of its efficiency and suitability. The case studies were analysed by measuring the effort (time) involved in and accuracy (quality) of decision-making. It helped us to understand how the system facilitated decision-making for different individuals, as well as to draw general conclusions and discuss the limitations and opportunities for decision support during emergency events. A specific analysis of the DRRT in the context of resource deployment was also conducted in order to identify its contributions and limitations for transport organisations such as New Zealand SHO.

1.5 Challenges and Original Contributions

Researching a complex topic like extreme events decision-making poses a series of challenges. Initially, scientific gaps were identified in order to clearly define research objectives and methods. For this research, in addition to the definition of research objectives and methods, we needed to specify data collection and analyses procedures as well as scenario implementation routines and case study set-up, which contributed to increase the challenges to be dealt with.

In this particular study we aimed at understanding the existing opportunities for decision support systems and expert systems in the context of emergency management. Practical needs observed during emergency situations (e.g. simulated exercises or real events) were considered when designing and developing the DRRT. Thus, we considered possible shortcomings of the conceptual interface between emergency management and decision-making support in our adoption of an appropriate research method. The DRRT development included defining data collection procedures and data analysis methods (to understand decision-making) in order to consistently support decision-making during emergency events. Scientific concepts from the literature as well as practical needs from the industry were essential in conducting the research and developing the DRRT.

The original contributions of this research relate to new methods and practices that can be applied in order to develop decision support tools for emergency management through a comprehensive understanding of extreme events decision-making. Observational methods, gaming simulations, decision-making theories, emergency management processes and information technologies all help to lay a robust research framework. Nonetheless, the design of the research framework and its application were still challenging due to the need to consider conceptual interfaces between emergency management and transportation, which have never been explored before.

Finally, this original method explores emergency decision-making using a combined engineering and cognitive framework, which ultimately attempted to fill the gaps in current practices. A deep cognitive decision-making understanding was achieved by observing organisations and staff during real and simulated emergencies. A complimentary game simulation supported better comprehension of physical deployment activities performed to respond to emergencies. Ultimately, information technologies, engineering optimisation models and experiences acquired over the observations and game simulation, were holistically combined in order to propose the DRRT.

1.6 Thesis Structure

This PhD thesis is divided into seven chapters in order to clearly describe all the activities undertaken during the research. After this introductory chapter, we present the complete literature review. The second chapter is dedicated to discussing concepts such as Emergency Management, the Decision-making Theory and Decision Support Systems/Expert Systems. Along with a technically-oriented review, we also discuss the opportunities to apply current techniques and Information Technologies in real emergency management situations.

The third chapter describes the research method applied to observe emergency exercises and real events in New Zealand. A deep understanding on organisational emergency management is achieved after taking part on the observation of four exercises and three real events since 2005.

Building upon findings from chapter 3, a game-based scenario simulation is proposed in the fourth chapter. This novel approach complement the data acquired in the third chapter as well as broadens knowledge on specific physical resource deployment activities. Both observations and game simulations target the identification of decision-making patterns and processes during extreme events. The comprehensive knowledge developed throughout chapters 3 and 4 is finally used to propose and describe the DRRT system.

The fifth chapter presents the development of the DRRT System. It initially describes the conceptual system along with information technology requirements and operational procedures. Both DRRT processes and logistics conceptualisation are discussed, using concepts identified in the literature review and decision-making knowledge gathered in the third chapter.

A series of case studies are introduced and analysed in the sixth chapter. It aimed at assessing the proposed DRRT system in order to identify its strengths and weaknesses in the context of New Zealand SHO. Hence, participants are presented with an emergency scenario and then their decision making accuracy (quality) and effort (time) are assessed. Complementarily, an analysis of logistics modelling routines proposed is performed in order to identify opportunities to support decision-making for resource allocation in transport networks. Findings from these experiences are considered, so that limitations in the current proposed system can be addressed in future research.

Finally, the last chapter summarizes the research and all the steps taken to reach its final outcomes: i) Comprehensive extreme events decision-making knowledge and ii) DRRT System proposal and assessment. A critical research analysis is conducted and both successes and limitations are reported so that future research recommendations can help to propose better system configurations and further evolve the collective understanding of decision-making during extreme events.

2 LITERATURE REVIEW

The intrinsic complexity of emergency events (e.g. conflicting priorities, resources limitations, community expectations, interdependent physical systems) requires the consideration of both practical and theoretical elements influencing decision-making during response and recovery activities. Thus, various disciplines and practical instances need to be considered in order to comprehensively understand decision-making under stress. In this context, this chapter presents the reader with a complete literature review on Emergency Management, Decision-making Theory and Decision Support Systems/Expert Systems. The review focuses on the identification and discussion of practical needs from the emergency management field and technical opportunities from the scientific literature in the context of decision-making and decision-making support. The chapter ultimately builds the basic knowledge necessary to achieve the main objective of this thesis, which is the development of the Dynamic Response Recovery Tool for roading organisations.

2.1 Emergency Management

Emergency Management (EM) has become a broad discipline dealing with risk management (i.e. mitigation and preparedness), response and recovery. Emergency Management Australia (EMA, 2009a) defines EM as "*a range of measures to manage risks to communities and the environment*". In spite to different approaches, EM usually aims at either avoiding a disaster (when it is possible) or reducing its impacts on communities and economies. Some EM frameworks have been identified as follows:

- Canada: effective since January 2005, the framework comprises Prevention and Mitigation, Preparedness, Response and Recovery (PSC, 2009);
- Australia: the national government refers to Emergency Risk Management, Disaster Mitigation and Consequence Management (EMA, 2009b);

- United States of America: the Federal Emergency Management Agency (FEMA) has a very comprehensive set of documentation for both public and businesses. Overall, it ranges from previous planning (Plan Ahead) to response and recovery (Recover and Rebuild); and

- New Zealand: the National Civil Defence Emergency Management Planning adopted the 4 Rs approach comprising Reduction, Readiness, Response and Recovery (MCDEM, 2009).

Emergency Management aims at disaster management and loss reduction by holistically considering relations between organisations and communities. The complexity of such emergency management activity has been illustrated in recent disasters such as the 1994 Northridge Earthquake, the 1995 Kobe Earthquake, the 2004 Sumatra Earthquake and Tsunami, 2005's Hurricane Katrina and the 2010 Haitian Earthquake. These events highlight the vast range of situations to be considered when managing disasters as well as limitations on current practices and processes.

Practical experiences have led researchers and practitioners into broad theoretical/practical scopes of emergency management. Several studies have been undertaken in the context of engineering, geology, psychology, policy making, resilience and many other disciplines. Outcomes from different fields have helped to frame EM under specific management structures aiming at co-ordinated response. Figure 2-1 illustrates a common management structure involving many organisations as well as basic activities to be performed while responding an emergency (e.g. logistics, operation, planning intelligence).

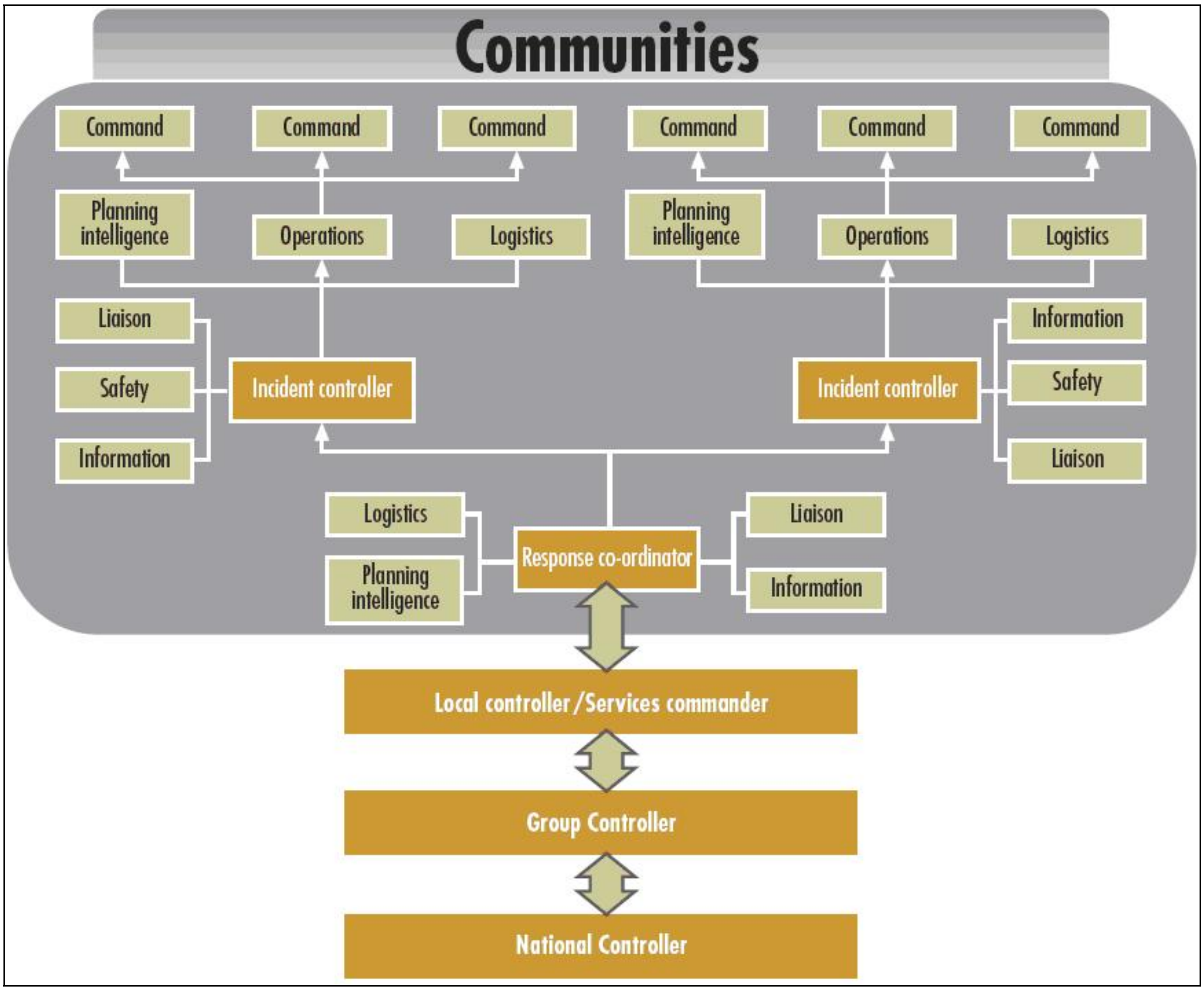

Figure 2-1: Multi-incident and Co-ordination Structure.
Source: Adapted from MCDEM (2009)

In spite to specific approaches, a co-ordinated management of an emergency can be achieved through clear information sharing procedures and response prioritisation. Although additional activities also need to be properly performed, information sharing among involved organisations along with specific event's needs and priorities play a key role for consistent emergency management.

Unfailing information flows and proper prioritisation take place when organisations and communities are well aware of the procedural platform to be implemented to respond an event as well as have available vital information to make decisions. As shown in Figure 2-1, links from the Central Government (National Controller) to Local Communities are established through Planning and Intelligence, Logistics and Operations commands. Hence, operational issues and national strategies can be holistically considered along with resources availability, international aid and local contingencies achieving great integration.

2.1.1 Emergency Management Concepts

A series of concepts is presented in this sub-section in order to explore different facets from Emergency Management. We start by defining emergency events and the four emergency management components, i.e. mitigation, preparedness, response, recovery/reconstruction. In closing, a discussion on integrated information sharing and logistics is presented.

2.1.1.1 Emergency Events

In order to define emergency events, we have to initially comprehend the meaning of hazard. Hazards are potential physical instances, phenomenon or human activity that can harm a community and create damage to its infrastructure (PSC, 2009). The Cambridge Dictionary also associates hazards with danger (an instance likely to cause damage) and risks (probabilities of events to produce harm or create damage) (Cambridge, 2008).

Disasters or extreme events are the result of the combination of hazards and vulnerabilities, which overwhelm community's ability to cope with the situation; therefore, incurs in loss of life and/or damage to infrastructures. The situation can be motivated by the geophysical or biological environment (natural disaster) or by human action or error (man-made disaster) (PSC, 2009). Stewart and Bomstrom (2002) summarize this conceptual topic by referring to extreme events as uncertain outcomes from either natural or man-made hazards, which creates potential damage and broad consequences to communities.

Finally, an emergency event represents a present or imminent disaster or extreme event, which prompts co-ordinated actions among people and organisations in order to protect life and/or property or reduce death and/or damage. Emergency events necessarily involve response and co-ordination towards risk reduction (for imminent disasters) or impact reduction (for present disasters).

In New Zealand, the Civil Defence Emergency Management Act 2002 (New Zealand, 2002) classifies emergencies as any happening that causes or may cause loss of life, injury, illness, distress or endangers life or property that require significant co-ordination response under the Act.

2.1.1.2 Mitigation

Mitigation involves pre-event actions taken in order to comprehend and reduce risks associated with hazards. The understanding of potential hazards reduces community's vulnerabilities and increases its ability to cope with disasters situations. PSC (2009) formally defines mitigation as "*sustained actions taken to eliminate or reduce risks and impacts well before an emergency or disaster occurs*".

Numerous frameworks and projects propose different paradigms for mitigation as it is acknowledged that future disasters cannot be exactly predicted. For instance, FEMA (2009) made available to the general public a standardised methodology and software (HAZUS-MH) containing models to estimate loses due to a number of events (e.g. earthquakes, flooding, hurricane). Additionally, the New Zealand approach presented in the National CDEM Planning (MCDEM, 2009) accounts for multi-agency mitigation supported by policies (CDEM Act 2002, National CDEM Strategy, National CDEM Plan and CDEM Group Plans) and the AS/NZS 4360 Risk Management Standard (2004)

In summary, mitigation can be defined as a group of actions taken before an extreme event in order to comprehend the relationships between communities (people and systems) and the surrounding physical environment. Such an approach has been already proven successful for disaster's prevention and reduction.

2.1.1.3 Preparedness

The second EM component focuses on readiness or planning. The Cambridge Dictionary (Cambridge, 2008) defines the adjective ready as being prepared and suitable for immediate activity. According to basic premises from emergency preparedness, organisations and people should exercise and plan in advance so they can be ready for immediate response.

A common framework used for preparedness refers to previous planning, mutual assistance agreements (aka memorandum of understanding), resource inventories, equipment and formal training (PSC, 2009). It ultimately consists of developing operational systems and capabilities before a disaster strikes (MCDEM, 2009) so effective response can take place. A practical three objective programme is proposed by the IFRCRCS (2002) comprising the following:

- To increase efficiency, effectiveness and impact of emergency response by developing regular training, system's testing and establishing clear policies;
- To strength community preparedness by supporting local population through National Programmes; and
- To develop activities addressing everyday risks faced by communities.

2.1.1.4 Response

The comprehension of risks (mitigation) along with response planning (preparedness) supports people and organisations to quickly and effectively respond to extreme events. Knowledge from the two previous emergency management components facilitates in defining the most appropriate response actions. It usually aims at reducing potential impacts associated with the occurrence of an extreme event according to specific situations, conflicting priorities and resources limitations.

Response is defined as co-ordinated actions taken immediately before, during or shortly after a disaster occurs. They refer to short term activities aiming at managing the situation through public communication, search and rescue activities, medical assistance, evacuation, well being/hosting and etc (PSC, 2009). Response activities are usually supported by systems (e.g. Co-ordinated Incident Management System – CIMS; Incident Control System – ICS), policies or response manuals, which ultimately targets reducing people's suffering and economic impacts.

Tools such as the ones cited above aim at operational co-ordination among public organisations (e.g. Fire, Ambulance, Councils) and private services (e.g. Power, Water, Telecommunications).

Thus, response and restoration times can be reduced as well as resources used at optimum levels. A good example of such an approach is the New Zealand's Civil Defence and Emergency Management CIMS (Devereux-Blum, 2010). It is a variation from NIMS – National Incident Management Systems (FEMA, 2010) and it is based on four core elements (known as control, planning and intelligence, operations and logistics). Been a multi-agency approach it aims at co-ordinated and effective response and recovery among involved organisations and general public. The previous understanding of risks and impacts (planning) helps in projecting future situations on real-time basis (intelligence) to effectively deploy/manage resources (operations and logistics). Finally, these activities are performed under strict levels of co-ordination (or control) involving a number of information sharing procedures among response organisations so conflicting priorities and resources limitations can be properly taken into consideration before resources can be deployed.

2.1.1.5 Recovery and Reconstruction

Also known as post-disaster response, recovery targets the reparation and restoration of communities and systems up to acceptable levels of operationability after a disaster occurrence. The MCDEM (2005) formally defines recovery as the "*immediate, medium and long term holistic regeneration of a community following a disaster*". Sullivan (2003) explores more this concept by describing recovery as activities undertaken immediately after the initial response, which bring self-sustainability to affected communities so external support frameworks and resources are no longer needed.

Moreover, reconstruction is classified as the recovery process at medium and long terms with focus on specific analysis of impacts and full restoration of a community and its environment (Brunsdon and Smith, 2004). Specific studies (Bhesram, 2007; Rotimi *et al.*, 2006) frame reconstruction into a five stage process: i) Impact Assessment; ii) Restoration Proposal; iii) Funding Arrangement; iv) Regulatory Process and v) Physical construction/reconstruction.

From the conceptual definitions of Response and Recovery, it is clear that there is an overlap between these two concepts. This is due to emergency management's components being fully integrated as a consequence of their dynamic nature. Been dynamic implies the need to consider EM as a cyclical interconnected process in which processes are shifted according to specific circumstances faced and needs (see Figure 2-2).

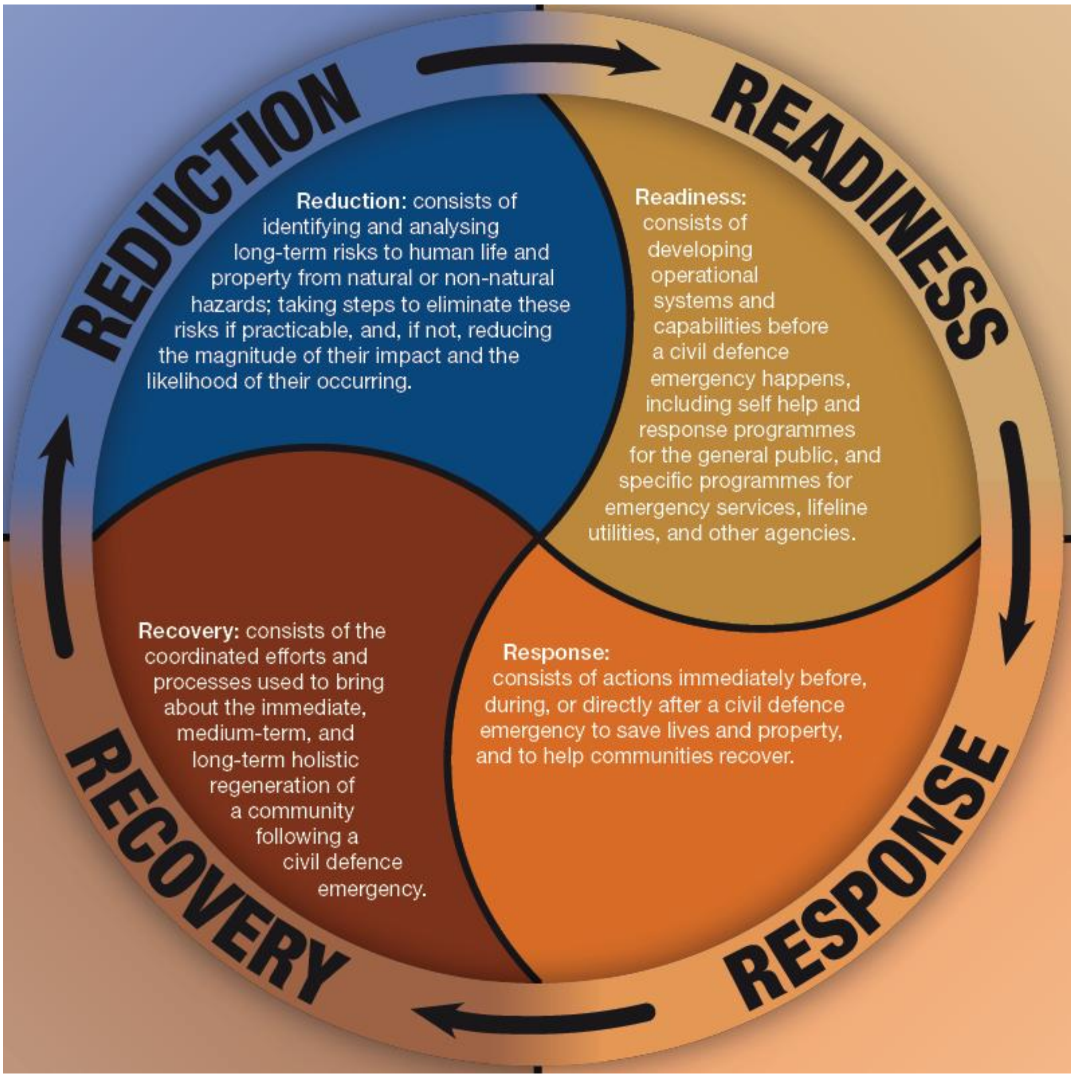

Figure 2-2: EM Components according to New Zealand's CDEM Planning.
Source: MCDEM (2009)

The interdependency of EM components creates the need for integrated Emergency Management platforms. This goal can be achieved by applying frameworks as the one illustrated in Figure 2-1, in which numerous organisations and communities are involved at different EM levels. In this backdrop, Emergency Management shall be holistically considered due to a vast range of activities to be performed such as preparation, training, response and recovery. Integration is finally accomplished using prominent information sharing procedures either at planning stages for developing accountability amongst involved parties or at response to improve decision-making and improvisation. This whole platform is geared towards proper resource deployment and management of conflicting priorities.

2.1.2 Emergency Management in the Context of Transportation

Emergency events present organisations with complex situations with risk to life, health, property and environment that require immediate response (Vedder, 1990; Fink, 1986; Berroggi and Wallace, 1995). Fredholm (1999) adds that quick response under changing conditions and unstable environments impose great challenges due to non-business as usual circumstances.

Particularly for transport networks, emergency management is of great interest. Recent worldwide events have demonstrated that the functionality of road transport networks to respond to disasters is vital in saving lives, reducing costs and enhancing the resilience of communities to recover from crises events. The New Zealand's Civil Defence Emergency Management Act 2002 (CDEM, 2002) emphasises that transport networks, among other key lifeline utilities (e.g. telecommunications, sewage, water, gas, power, fuel), need to be able to function to the fullest possible extent during and after an emergency event.

Transportation researchers have tackled different topics such as shortest path selection (Cherrie and Dickson, 2006; Fu *et al.*, 2006; Liu, 1997; Liu et *al.*, 2006a; Liu *et al.*, 2006b; Takeuchi and Kondo, 2003), network reliability (Nicholson, 2007), risk assessment (Asakura, 2004; Dalziell and McManus, 2004), evacuation modelling (Fu *et al.*, 2007; Moriarty *et al.*, 2007) and Geographic Information Systems (ESRI, 1999).

This range of studies has developed very consistent knowledge on how emergencies can be better managed throughout mitigation, preparedness, response and recovery. For instance, information need is defined in lifeline studies (Dantas *et al.*, 2007), data analysis methodologies scrutinized by logical and mathematical models and data gathering and representation performed by spatial information systems such as GIS.

These advances have ultimately paved the way towards integrated applications. Kepaptsoglou *et al.* (2007) report a very interesting application including web communication and decision support to manage bridged networks. Mendonça and Wallace (2007), Mendonça *et al.* (2001) and Mendonça *et al.* (2006) have used Decision-making Theory to study emergency management decision support and improvisation. However, these numerous findings are yet to be considered by the transport community.

The inclusion of decision-making paradigms along with identified opportunities from modelling (e.g. evacuation, short paths, network reliability, risk assessment) and information technologies (e.g. GIS, Decision Support Systems/Expert Systems, Web communication) have drawn a new research prospect, which is under investigation in this thesis. This trend is further explored in the next section by presenting and discussing Decision-making theory concepts in the context of emergency events.

2.2 Decision-making Theory

The American Heritage Dictionary (2000) defines "decision" as the act of passing judgment on an issue under consideration, reaching a conclusion and pronouncing a verdict. The Cambridge Dictionary (2008) refers to the verb "decide" as the act of "choosing something after thinking carefully about several options" and the noun "decision" as the "ability to decide quickly and without pausing because of uncertainty" (Cambridge, 2008). Chiang-Hanisko (2002) finally defines "decision-making as a method of choosing among potential possibilities, including possible actions, beliefs and personal goals".

Numerous studies can be found in the context of decision-making in different fields (e.g. Operational Research – Charnes *et al.*, 1978; Business/Operations Research – Bell, 1982; Political Sciences – Tsebelis, 1995; Psychology/Cognitive Sciences – Busemeyer and Townsend, 1993).

The common factors considered are human components (e.g. knowledge, memory, cognitiveness, experience, expertise etc) used during the identification and assessment of decision-making choices.

This section reviews decision-making concepts and models with special focus on emergency management. It is initially presented a quick overview on decision-making theories in order to discuss suitable models in the light of the emergency management. The section is closed with a discussion about expertise in the decision-making processes.

2.2.1 Overview

Research conducted indicated that decision-making does not have a single definition. Its definitions range from cyclical process in which assets (physical resources plus abilities and skills), utilities (estimated satisfaction value associated to each possible decision) and outcomes (possible consequences) are interactively considered (Levin and Brazil, 2008). The process aims at selecting actions to advance people's welfare according to everything known and felt (Brown, 2005).

For the specific aim of this research, we define decision-making as processes in which agents (e.g. individuals, organisations, governments) identify options and project outcomes according to their best knowledge and information as well as available time and resource limitations. It is reinforced that this definition cannot be taken as absolute as extreme events are characterised as having many involved agents. Some authors state that decision-making during extreme events is a complex and ill-structured problem (XE, 2002).

Numerous studies have already been devoted in understanding extreme events decision-making (XE, 2002). Findings regard to the identification of linear and non-linear models, social and organisational factors, human behaviour (e.g. stress, emotion) etc. In this light, a range of decision-making models are presented and specified in the literature (Stacey, 1996 *apud* Firestone, 2008a; Brown, 2005; Hastie and Dawes, 2001 *apud* Levin and Brazil, 2008; Levin and Brazil, 2008; Zsambok and Klein, 1997; Saaty, 1996; Sinha, 2005). They are products of different research endeavours aiming at clarifying principles and procedures "between the agent's goal state and the actual state of the world the agent is trying to manage" (Firestone, 2008a). The next sub-section narrows down decision-making studies into the emergency management discipline in order to specify the conceptual range to be dealt with.

2.2.2 Decision Making Models in the Emergency Management Context

Emergency management activities involve cognitiveness due to extreme events being fundamentally complex ill-structured phenomena (XE, 2002). Decision-making approaches in this context commonly tackle cognitiveness by considering knowledge, experience, logical reasoning, mathematical analyses etc. Additionally, urgency in decision-making during disasters emerges from so-called Golden Hour, Golden Ten Minutes (McDonald *et al.*, 2006) and 72 Hours rules. These paradigms claim that lives can be likely saved if hospital care and first aid are provided to victims within a short time spans defined by event's type and consequences.

In the specific emergency management context, among a number of decision-making models found in the literature, we have identified two suitable techniques for the case of emergency management: i) Normative Decision Model and ii) Naturalistic Decision Model. These models come from general frameworks such as Observe-Orient-Decide-Act (OODA) Cycle (Boyd, 1987) and Decision and Learning Cycles (DLC). Conceptual representations of cognitiveness associated with both frameworks provide the necessary flexibility to understand emergency management.

On one side of the spectrum, the Normative decision model (or prescriptive model) aligns with the classical decision-making theory. In this model the decision maker presume a "rational" agent, fully informed, who examines a set of alternatives and weight attributes in order to make the "best choice". On the other side of the spectrum, the Naturalistic Decision Model has recently emerged as a complementary model to the Normative Decision Model. It incorporates complex cognitive functions performed in demanding situations, e.g. time restriction, uncertainty, vague goals, high stakes, team and organisational constraints, changing conditions.

Recent research has shown that emergency events are characterized by dynamic conditions, in which conflicting priorities, multiple actors and different levels of information reliability and availability play major roles. Therefore, people do not conform to a normative decision model, being more likely to use simple heuristics and to display systematic biases in their decision process (Tversky and Kahneman, 1981). For instance, research conducted in the military environment (Klein, 1989) found that the very language of decision models is difficult to translate into operational settings. Numerous decision makers interviewed rejected the notions that they were "making choices", "considering alternatives" or "assessing probabilities". Instead, they saw themselves as acting and reacting on the basis of prior experience, generating, monitoring, and modifying plans (i.e. improvising) to meet specific needs arising from different situations. In other words, experts use their experience to make rapid and effective decisions under time pressure and uncertainty.

Complimentarily, the conventional methods prescribed by the normative decision-making (e.g. deductive logical thinking, analysis of probabilities, and statistical methods) were not perceived useful during emergencies due to limited power of intuition and mental stimulation (Kaemps *et al.*, 1993; Klein, 1998). Normative decision models are more likely to be applicable for well defined problems, in which there is plenty of time for options evaluation and limited pressure (Endsley and Jones, 1997).

In this context, the following sub-section summarizes key fundamentals for the Naturalistic Decision Model due to its suitability for emergency management.

2.2.2.1 Naturalistic Decision Model

Dreyfus (1981) and Sweller (1988) cite that under pressure and uncertainty, decisions are made using a process of situation recognition and pattern matching to memory structures and prototypical situations. Human behaviour research conducted by the New Zealand Fire Department (NZFD, 2009) highlights that under time pressure humans employ "situation satisfying processes", which are more efficient than optimization procedures. This process conforms to the Naturalistic Decision

Model, in which pattern matching draw upon long term memory (Endsley, 1995b) and prototypical situations supports instantaneous situation classification under specific schemes (Endsley and Garland, 2000).

In this light, three cognitive functions were defined in the context of Naturalistic decision-making models:

- *Situation awareness*: the perception of elements in the environment within a volume of time and space. The comprehension of their meaning and the projection of their status in the near future considering possible actions to be taken (Endsley 1988);

- *Sense-making*: the interpretation of equivocal cues into meaningful narratives (Weick 1995; Lamertz 2002). It is a social activity whereby, through multi-contextual conversations, sense is constructed, destructed and reconstructed in an on-going attempt to craft, understand and accept new conceptualizations prior to consistently act according to new interpretations (Kezar and Eckel, 2002); and

- *Planning*: an integral part of the sense-making process dealing with the visualisation of alternative futures.

Situation awareness shows to be of great interest in the context of emergency management. It represents ways that "*people interpret sensory stimuli received by their environment*" (NZFD, 2009). This is the process in which decision-making agents use knowledge and information to comprehend current instances and project future intended states of the world. As Figure 2-3 illustrates it is a cyclical process where sense making and planning are also performed before decisions are chosen and implemented. New instances unfold due to previous actions so the situation awareness shall be updated in order to support upcoming decision-making activities.

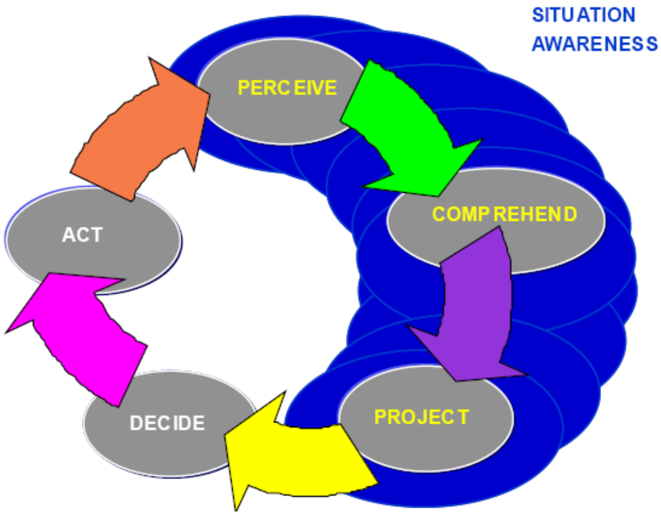

Figure 2-3: Situation Awareness in the Decision-making Loop.
(Endsley, 1995b).

2.2.3 Expertise in the Context of Emergency Management Decision-making

The Naturalistic Decision Model and situation awareness process indicate links between emergency management decision-making and knowledge. The Oxford English Dictionary (1999) defines knowledge as expertise and skills acquired by experience or education and awareness as familiarity gained by experience or collection of facts and information.

According to the Naturalistic model, decisions are made under a situation recognition process. It is reliant on the decision maker's memory (or accumulated knowledge), which comprises a series of situation prototypes and their respective scripted actions (Figure 2-4). The memory component starts operating after initial information about the situation is given to the decision maker. Actual situations and experienced instances are compared and intended to be matched. After commonalities between previous and current realities are identified, decisions are made accordingly to scripted actions, i.e. successful actions performed in the past. Note that decisions can also be made if similarities are not found in the memory component. In such cases, they are motivated by a human capacity of improvisation.

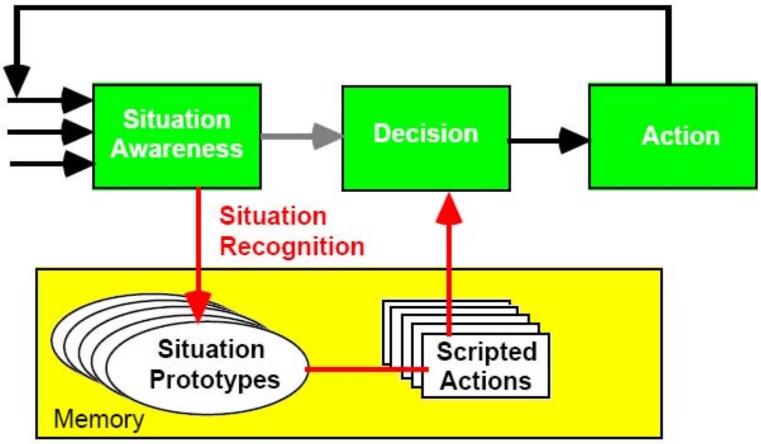

Figure 2-4: Role of Situation Recognition and Scripted Actions in the Decision-making Processes. (Cheah *et al.*, 2000)

For instance, in a particular scenario of an earthquake consider the destruction of an isolated and sparsely populated area and the collapse of several main road infrastructures. Initial reports from the affected area indicate that people suffered minor injuries, but there were significant damage to major infrastructures. Given this initial level of situation awareness, the decision makers draw back on their memories for similar events in order to identify a case or circumstance (situation prototype) that mostly resembles the current event. Once matches are found, the decision makers associate the case or circumstance to what were the most efficient or useful actions previously taken or recommended (scripted actions). This could be the immediate deployment of resources for main road infrastructures repairs, open access for external resources deployment, invest on allowing air transportation into the affected area, ensuring business support and property protection etc. Ultimately, the decision makers reach a decision point in which field actions are decided and further implemented.

Clearly, situation recognition places considerable value on how decision makers use their memories (or knowledge base) when dealing with extreme events. The decision maker's capacity to perform "situation recognition" is heavily influenced by experience and expertise. On one hand, the decision maker is only capable on drawing on his/her knowledge base if he/she has had proper training or instruction on the relevant matter. On the other hand, experienced decision makers, more then novices, are able to carry out their tasks even when faced with uncertainty, e.g. missing, ambiguous or unreliable information.

Within the common uncertain environment in which emergency managers operate, we have decided to investigate possible opportunities from Information Technology (IT). It has been found that recent advances in IT have targeted decision support by comprehending situation recognition processes. Cannon-Bowers and Bell (1997) highlight that experts are able to quickly recognise an entire pattern during a decision-making processes by using their expertise. Hence, applications such as Decision Support Systems (DSS) and Expert Systems (ES) can be employed under the knowledge-base paradigm in order to facilitate decision-making for inexperienced decision makers, during inexperienced situations and highly demanding emergencies. Such IT tools are further presented and discussed in the next section to build the necessary knowledge to develop the proposed Dynamic Response Recovery Tool.

2.3 Decision Support Tools for Emergency Management

The review of Emergency Management concepts and Decision-making Theory has indicated the need to identify suitable techniques to support decision-making during emergency events. Two techniques (namely Decision Support Systems and Expert Systems) have initially shown potential to incorporate emergency management needs and decision-making theories within a theoretical framework, which could be further used to propose and develop the Dynamic Response Recovery Tool (the main objective of this thesis).

2.3.1 Decision Support Systems

A growing number of organisations have been developing, implementing and improving Decision Support Systems (DSS) in recent decades. However, objectives, structure and decision-making support may vary considerably among applications (Sprague and Watson, 1986). Some authors claim that DSS has no formal theory and it is just another “buzz word” to replace Management Information Systems (Sprague, 1980 *apud* Sprague and Watson, 1986). Sol (1987) states that DSS is a label to the philosophy on how to integrate tools and human judgement. Another insight is given by Power (2007) who highlights that DSS have focus on semi or unstructured problems while Management Information Systems (MIS) have an information focus on structured problems.

In this extensive and complex background, the following review discusses DSS concepts, history and frameworks. This section is limited in presenting technical components needed to develop the DRRT.

2.3.1.1 Definition

Power (2005a) defines DSS as any specialized system that support decision-making. DSS are systems aiming at facilitating decision processes and supporting (but not automating) decision-making to quickly respond to changing needs that decision makers commonly experience in practice (Power, 2002) . Alternative concepts found in the literature define DSS as computerized information systems that supports business and organisational decision-making by helping to process/compile information from raw data, documents, personal knowledge, and/or business models (Information Builders, 2008). Decision Support Systems are also generally described as systems that gather and present data from various sources and properly combine multiple Information Technologies (IT).

In this vast conceptual environment, different applications are labelled as DSS (Power, 2005a and BTM and KM Research Network Web Site, 2007). Few examples of DSS are OLAP (On line analytical processing), data warehouses, optimisation models, visual simulations, GIS (Geographic Information Systems), desktop data bases with query tools, PSS (Planning Support Systems), PDSS (Planning and Decision Support Systems), BI (Business Intelligence).

From the above it is clear that a single DSS definition would not extensively exhaust the paradigms associate with DSS. Therefore, numerous researchers simply consider DSS as computerized information systems that support businesses and organisations to make decisions (Power, 2005a). This general definition gives the necessary flexibility to consider communication technologies, data/document/knowledge processing tools, problem solving models and decision processes (DSSR, 2007) in order to achieve the ultimate goal of efficient decision-making support.

2.3.1.2 History

The history of DSS formally starts at the mid sixties. Concepts and paradigms have considerably evolved due to technology and human resources advances over the past five decades. Table 2-1 summarizes what have been experienced in terms of DSS development since its first developments up to present days.

Table 2-1: Decision Support Systems History.
Modified from Sol (1987) and Power (2002).

Period	Characteristics
Prior to 1965.	It was very expensive to build large scale information systems. At this stage Management Information Systems (MIS) were only observed in large companies.
Late 60's.	Concepts of DSS evolved from studies conducted at the Carnegie Institute of Technology and the Massachusetts Institute of Technology (MIT). Model Oriented DSS or Management Decision Systems were the main achievements in this period.
Early 70's.	A great number of computerized based systems were developed aiming decision-making aid.
Mid to late 70's.	DSS research focused on developing interactive computerized based systems. Data base management and decision models were used to aid solving ill-structured problems.
Late 70's.	Practitioners, vendors and academics promoted a consistent development of DSS.
Late 70's to early 80's.	Strong efforts in developing user friendly software to improve the effectiveness of managerial and professional activities.
Early 80's.	Created the theoretical framework for developing knowledge-oriented DSS.
Late 80's.	Convergence to use of Artificial Intelligence (AI) paradigms to emulate human reasoning. Initial developments of Expert Systems (ES).
Mid 90's.	The introduction of Data Warehousing and the World Wide Web impacted the course of DSS development.
Late 90's.	"The data warehouse became the cornerstone of an integrated knowledge environment that provided a higher level of information sharing across an organisation, enabling faster and better decision making" (Professor Philip Powell *apud* Power, 2002).
Present	A number of academic disciplines such as database research, management science, cognitive science, artificial intelligence, software engineering etc stimulated the DSS development.

Table 2-1 shows that DSS have experienced progressive developments throughout time. Simple concepts have developed into complex and well fundamented techniques (e.g. Artificial Intelligence) through academic research and industry development. Easier and cheaper access to computers and efficient data processing tools were also facts that motivated the popularization of DSS.

In this backdrop, DSS projects can be successfully developed nowadays. The actual flexibility associated with DSS development has defined three methods, namely DSS Generator, DSS Shells and Customer Made Software (Singh, 2007). These methods allow the development of DSS from a simple external data base connection into a pre-programmed framework application (commonly referenced as DSS Shells) to complete customizable applications. This range of possibilities has empowered both small and big organisations to develop DSS applications according to specific needs. A few frameworks are presented and discussed as follows as a practical illustration on how the DSS technique can be applied in the development and deployment of decision support applications.

2.3.1.3 Decision Support System Frameworks

The American Heritage Dictionary (2008a) defines “framework” as a fundamental structure that contains a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality. A Decision Support System Framework represents a structure, in which interfaces among four components (namely data base, model, communication and user interface) are linked in order to produce and present outcomes designed to facilitate decision-making.

Figure 2-5 illustrates a basic DSS Structure along with the existing relations among the four components abovementioned. External and internal data sources feed the Data Base Component with information needed by the system. The data base component ultimately represents knowledge, current situations, rules/procedures, regulations, etc. External/internal data is processed by the Model Component, which contains models and a computational application, namely Inference Engine. This processing stage aims at replicating human reasoning and emulating knowledge so burden on decision makers can be reduced. Outcomes from data processing are transferred to a Communication Component, which prompts the information in different interface units. Finally, the Interface Component transforms the information received into ease representation formats such as charts, graphs, maps, reports, etc. The end-user receives the information in its final representation format and uses it according to his/her best convenience. We reinforce that DSS do facilitate, not automate, decision-making and do not replace the human decision maker as highlighted by Power (2005a).

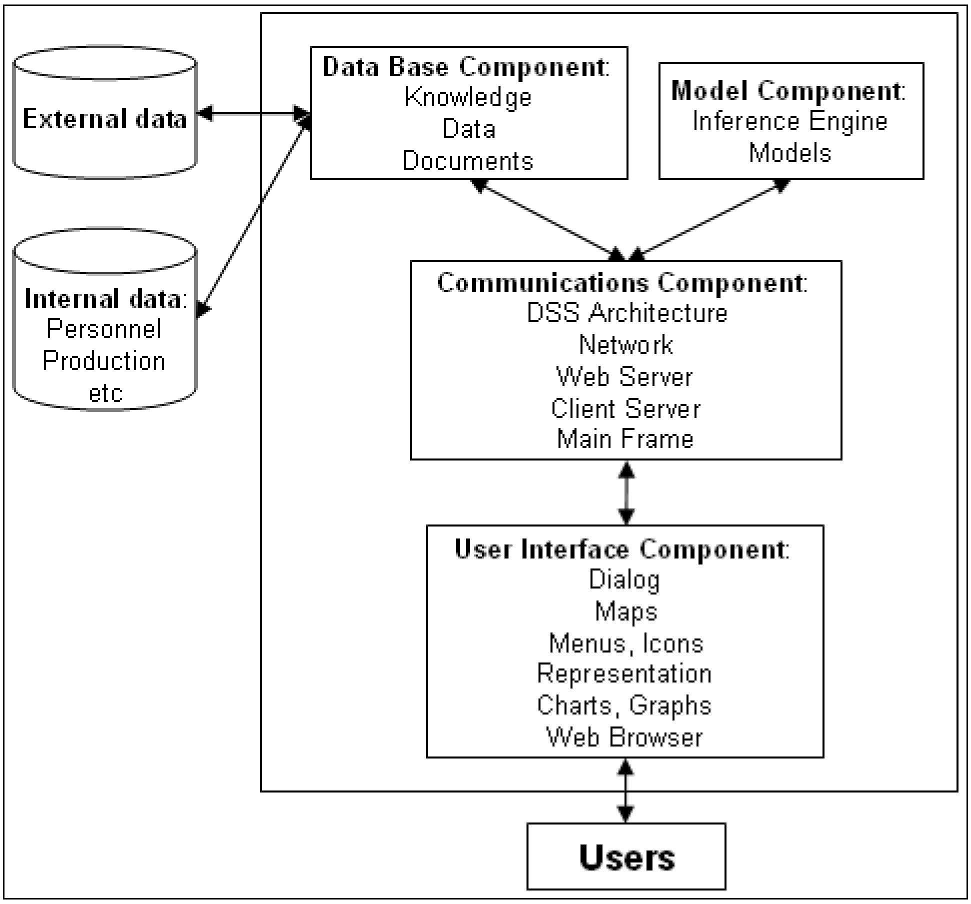

Figure 2-5: DSS Basic Structure.
Source: Power (2005a).

Different frameworks are cited in the scientific literature in order to facilitate the process described in the last paragraph. Power's Expanded Decision Support System Framework (Power, 2002) presents a very comprehensive set of five frameworks as follows:

- Data-driven DSS: Used for the analysis of large amounts of structured data. It provides tools to access and manipulate different data types (e.g. time series, spatial). It commonly has functionabilities such as query and retrieval, which provide simple data aggregation, management and calculations;
- Model-driven DSS: Systems embedded with numerous models like accounting, financial, representational and optimisation. Complimentarily, statistical and analytical tools provide an elementary level of data analysis. Model-driven DSS mainly aid decision makers in the analyses of situations, which data is already available so they are non data intensive systems (i.e. do not consider data collection methods) as data must be available either from the end user or from a given database;
- Knowledge-driven DSS: The terminology for these systems is still evolving. Knowledge-driven DSS, Suggestion DSS or Management Expert Systems (MES) are different acronyms used to refer to those systems. They mainly generate suggestions and/or recommendations of actions to end users. To do so, a set of rules and a knowledge base are combined in order to represent a specific expertise capable to infer problems; therefore, facilitate decision-making. The concept of expertise refers to particular knowledge and skills used to solve problem on specified domains;
- Document-driven DSS: Recently, this particular framework has experienced a great development. It aims at helping managers to gather, retrieve, classify and manage unstructured documents. Document-driven DSS involves a variety of technologies that allow document retrieval and analysis. Possible applications refer to both governmental and private sectors in accessing policies, procedures, products specifications, catalogues, etc; and
- Communication-driven DSS: It is a hybrid DSS that uses both communications technologies and decision-making models. They are computerized based

systems intended to support group decision-making by facilitating problem inference and decision/information sharing. It is developed by taking advantage of opportunities from communication and computer science technologies. Common applications regards to electronic communication, scheduling, document sharing among others.

From the frameworks previously described, it is clear that decision-making can be aided using a different set of resources depending on problems faced and available information. In this context, DSS does not automate decision-making as it deals with ill-structured problems as optimum courses of actions are seldom identifiable.

2.3.2 Expert Systems

The Expert System (ES) paradigm has been identified as a significant topic while conducting the Literature Review on DSS. Similarly to DSS, Expert Systems are used to design decision support tools; however, they are more oriented towards knowledge representation and management. It can be ultimately classified as a Knowledge-driven DSS due to its knowledge representation and management approach. We further present a brief history, background, fundamentals and basic structures of Expert Systems in order to clarify the differences and commonalities with DSS as well as potential opportunities for ES to be used in the DRRT development.

2.3.2.1 History

Some authors recognise that the first developments in Expert Systems theory were made in the seventies, while others point Artificial Intelligence studies as the formal ES origin. This debate comes from the fact that ES and AI have similar foundations so splitting their development into two different streams would be unrealistic.

Despite this debate, ES progress experienced a great development in the seventies due to the conception of the knowledge base paradigm. Expert Systems have proven to be able to represent reality through knowledge management theories by using “a set of assumptions, concepts, values, and practices” (The American Heritage Dictionary, 2008b).

The development of standard knowledge representation methods, have motivated academia and industry to deploy ES in many fields. For instance, the PROSPECTOR was used to find a mineral deposit worthing at its time about US$ 100 million. The XCON/R1 helped Digital Equipment Corporation to save millions of dollars a year by optimising the time to configure and improving accuracy in purchase orders so shipment delays and reconfiguration needs were considerably reduced.

However, the big “boom” experienced during the seventies was interrupted in the early eighties due to high costs associated with AI Laboratories. At this time, setting up and running a laboratory with six programmers was estimated in half million American dollars (Power, 2007). Considerable efforts to develop simple and efficient programming languages were put in place by the National Aeronautics and Space Administration (NASA). The goal was to reduce human resource needs and improve system’s development and performance. NASA developed the CLIPS Language, which is written in C Language and has advantages such as high programming speed, portability and compatibility with the Rete Algorithm for pattern matching.

Actions towards reducing human efforts were also observed with other software products such as ES shells. An ES Shell allows users to focus on the development of the Knowledge Base rather than on technical computational details like programming, debugging and graphical interfaces. The EMYCIN (Empty or Essential MYCIN) is one of many examples of ES shells that are commercially available. Expert System’s shells are formally defined as a special propose tool designed for specific applications in which the user must only develop the knowledge base (Giarratano and Riley, 1998).

In the recent decade, the Expert System Theory has been paving its way on the basis of the symbolic reasoning. However, non-numerical programming basis associated with the recent computational developments (both software and hardware) have brought new challenges for researchers and professionals. Similarly to past decades, human resources constraint project budgets and development regardless physical resources been considerable accessible due to popularization of computer hardware and software.

Ultimately, trade-offs between outcomes (both social and economic benefits in using ES) and investment needed to develop ES are key assessment measures in deciding to develop an Expert System. It is also needed to consider that symbolic programming cannot always achieve an efficient generalization of ill-structured problems due to domains been hard to be properly defined and unexpected inputs usually common (Giarratano and Riley, 1998).

2.3.2.2 Background

Expert Systems and Decision Support Systems originated from the Artificial Intelligence (AI) studies during the sixties and seventies. Mostly, AI focuses on emulating human behaviour by modelling reasoning capabilities. AI can also be used to represent and to manage knowledge.

The development of Expert Systems began with Feigenbaum and others at Stanford with the Heuristic Programming Project (HPP) (Pomykalski *et al.*, 1999). A good example is the MYCIN System, which performs about 450 rules to diagnose blood infections. During its time, the MYCIN performed similarly to experts and considerably better than some junior doctors (Pomykalski *et al.*, 1999). However, it has never been used in practice due to legal and ethical issues concerning medical practices.

Similarly to Decision Support Systems, Expert Systems can be broadly defined. The following list presents the most popular definitions found in the international literature:

- Computer programs designed to make available to non-experts some skills of an expert (Siler and Buckley, 2004);
- Software designed to mimic the decision-making ability of an expert decision maker in a particular narrow domain of expertise (Pomykalski *et al.*, 1999);
- Reasoning systems designed to replicate problem-solving techniques of an expert in a narrow area of specialism (Beerel, 1987);

- Intelligent computer programs that use knowledge and inference to solve problems (Feigenbaum, 1892 *apud* Giarratano and Riley, 1998);
- Systems that emulates the decision-making ability of a human expert (Giarratano and Riley, 1998); and
- Systems that address problems normally thought to require human specialist to be solved (AIM Expert Systems, 2008).

Generally, Expert Systems aim the representation of knowledge in order to achieve the goal of decision support. They are systems that represent in structured ways (i.e. pre-defined schemes) the top level of the pyramid illustrated in Figure 2-6. Knowledge is developed through a process of refining expertise. According to Jackson (1999), expertise is a set of skills that have been honed in a particular situation for a specific purpose or domain. Finally, expertise originates from information, which is obtained via data processing under specific paradigms of syntax and semantic, analysis methods and/or models. Note that this process is dependent on time as transforming data into knowledge demands well structured methods, numerous experts as well as physical resources and appropriate funding accordingly to particular projects and objectives.

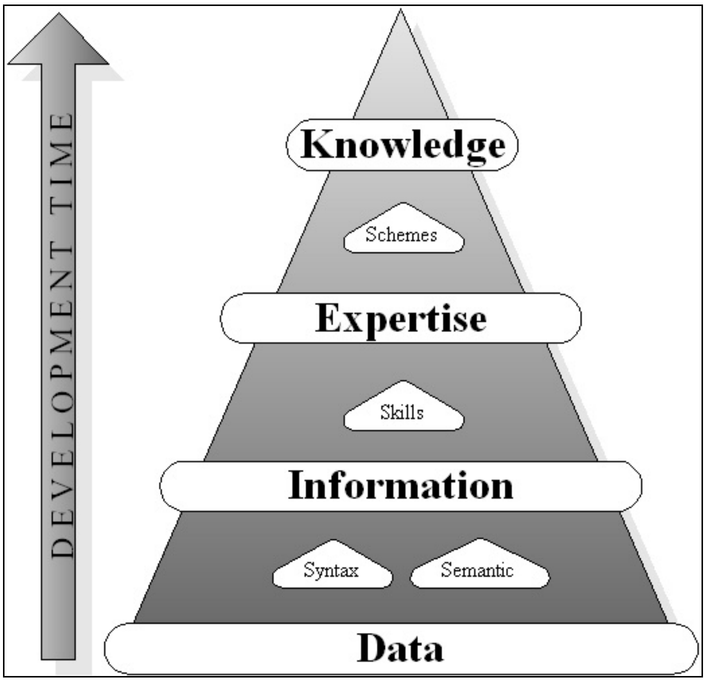

Figure 2-6: Knowledge Development.

Figure 2-6 shows that knowledge representation can be applied in many fields due to conceptual depth. Thus, the use of Expert Systems can support numerous problem-solving tasks as their knowledge base structure allows the integration of human expertise and computing facilities (Badiru and Cheung, 2002). Pomykalski *et al.* (1999) state that ES can contribute to decision-making activities through knowledge representation as: i) it preserves human expertise by recording it in long-lasting ways; ii) it allows humans to be freed from performing routine/time consuming activities and iii) it provides support in performing complex activities.

However, Siler and Buckley (2004) state that representing knowledge is a complex and critical stage in developing any ES application. For instance, the definition of criteria and actions to be triggered in IF/THEN rules (a common structure in many Expert System's Inference Engine) can consume lots of human effort and time depending on the field and on the expertise level. Thus, a successful development of an ES must consider factors such as the nature of the application (e.g. engineering, management, medical), availability and need to develop knowledge, analyses skills, development/deployment time-frame, accuracy of results and available budget.

Hence, achieving a good level of knowledge representation is undoubtedly a fundamental step in developing Expert Systems. Once it is accomplished, an alternative supporting source for decision-making is available. Jackson (1999) cites that well developed ES have great chances to suggest recommendations in a reasonable time and be regularly or at least as often correct as human experts. Moreover, an ES application must be seen as an alternative source of information, which does not intend to replace the human decision maker as intelligent systems are still limited when compared to human beings. Inaccuracies (fluctuation in performance) are expected and efficient systems can originate from designs using both facts and heuristics under hierarchical analysis processes (Badiru and Cheung, 2002).

2.3.2.3 Fundamentals

Four basic concepts comprise what specialists refer as fundamentals of Expert Systems. The concepts vary from the way that knowledge is acquired from experts and represented within computerized systems to how the system can explain the reasoning used to achieve solutions. Figure 2-7 shows the four fundamentals concepts and the relationships among them. The process of developing an Expert System starts with the knowledge acquisition and finishes with the development of the solution explanation component. Intermediate phases are known as Knowledge Representation and Reasoning Controlling.

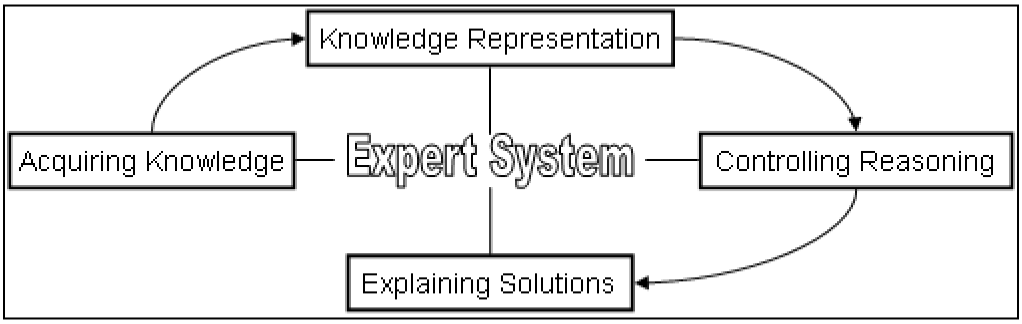

Figure 2-7: Fundamentals of Expert Systems.

Knowledge acquisition or machine learning is defined as the transformation of potential problem-solving expertise from a knowledge source to a computer program (Buchanan *et al.*, 1983 *apud* Jackson, 1999). The knowledge source is ideally a human expert; however, alternative sources (e.g. books, manuals, raw data) are also used as human experts can imply high costs or being unavailable.

As highlighted by Siler and Buckley (2004), this activity is recognised as the bottleneck of Expert Systems as it can demand too much time and/or resources due to poor productivity. This is a direct consequence from facts and principles being many time ill-structured; therefore, hard to be modelled and represented by mathematical or cognitive theories. Feigenbaum (1977) *apud* Jackson (1999) states that both mathematical and cognitive theories cannot many times consider at full extend human's expertise and associated problem solving capabilities. This is ultimately a consequence of decision-making being very complex and abstract subject.

After knowledge is acquired, it must be structured in standard ways. Knowledge representation comes from the formal philosophy and cognitive psychology (Jackson, 1999). Computationally, the effort focuses on representing knowledge using symbolic or non numeric computation. This is done by making use of programming languages, which contains syntax (forms) and semantic (meanings). A well known language to build ES is the C Language Integrated Production System (CLIPS) developed in the eighties by NASA (GHG Corporation, 2008). Nowadays, alternative programming languages can also be used to build ES (e.g. FORTRAN, C++, C Sharp, Ruby etc), which reflects the great computational development experienced in the last two decades.

“Controlling Reasoning” refers to determine how knowledge should be accessed and used during the search for solutions or data processing. It is formally set up in the inference engine, which contains the implementation algorithm responsible for operationalising the system. The final fundament (solution explanation) specifies how conclusions were achieved and what pieces of knowledge were used. This final process is important in order to give transparency to the system (meaning, ES are not meant to be black box tools) and to allow the user to evaluate proposed solutions or recommendations according to his/her needs.

Finally, Table 2-2 summarizes the key characteristics of an Expert System according to Beerel (1987). It reinforces that Expert Systems are computer tools, which intend to replicate human decision-making skills through representing knowledge within rule base components. Furthermore, it is explicit that errors and inaccuracies are expected as human knowledge is too vast and hard to be entirely modelled by currently available frameworks and computer paradigms.

Table 2-2: Expert System’s Key Characteristics.
Source: Adapted from Beerel (1987).

ES system manipulates symbols rather than numbers.
ES system makes inferences and deductions from the information provided.
Knowledge is applied to solve problems.
Problem’s domain is narrow and specifically defined.
Knowledge-Base is used to guide and constrain search for solutions.
Optimum solutions are seldom identified due to the complex nature of problems

2.3.2.4 Structure

An Expert System application contains two basic components: a Knowledge Base and an Inference Engine. Operationally wise, a dynamic relationship between user and system occurs as illustrated in Figure 2-8. The system uses data and facts provided by the user and return expertise. Outcomes (e.g. recommendations, solutions) are generated after inputs are processed by engaging the existing set of rules within the knowledge base. The inference engine contains the operational algorithm, which selects the most applicable rule(s) accordingly to particular situations represented by data/facts. Giarratano and Riley (1998) formally describe the inference engine as the component responsible to execute and prioritize rules accordingly to inputs received from the user.

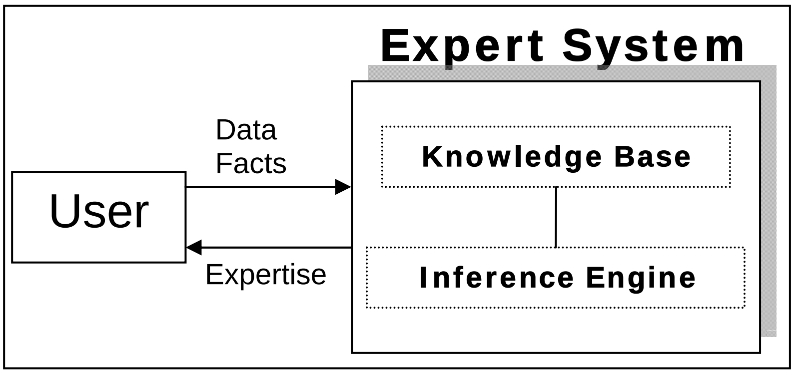

Figure 2-8: Expert System Structure and User Relationship.
Source: Giarratano and Riley (1998).

Although the simple and straight forward description provided in the last paragraph, additional ES structures need to be properly defined. Berkes *et al.* (2001), Giarratano and Riley (1998), AIM Expert Systems (2008), Biondo (1990) and Arockiasamy (1993) are well known authors, which propose slightly different ES structures. Among these structures, we have identified Berkes' *et al.* (2001) proposal as the one most suitable for the specific development of the DRRT (Figure 2-9)

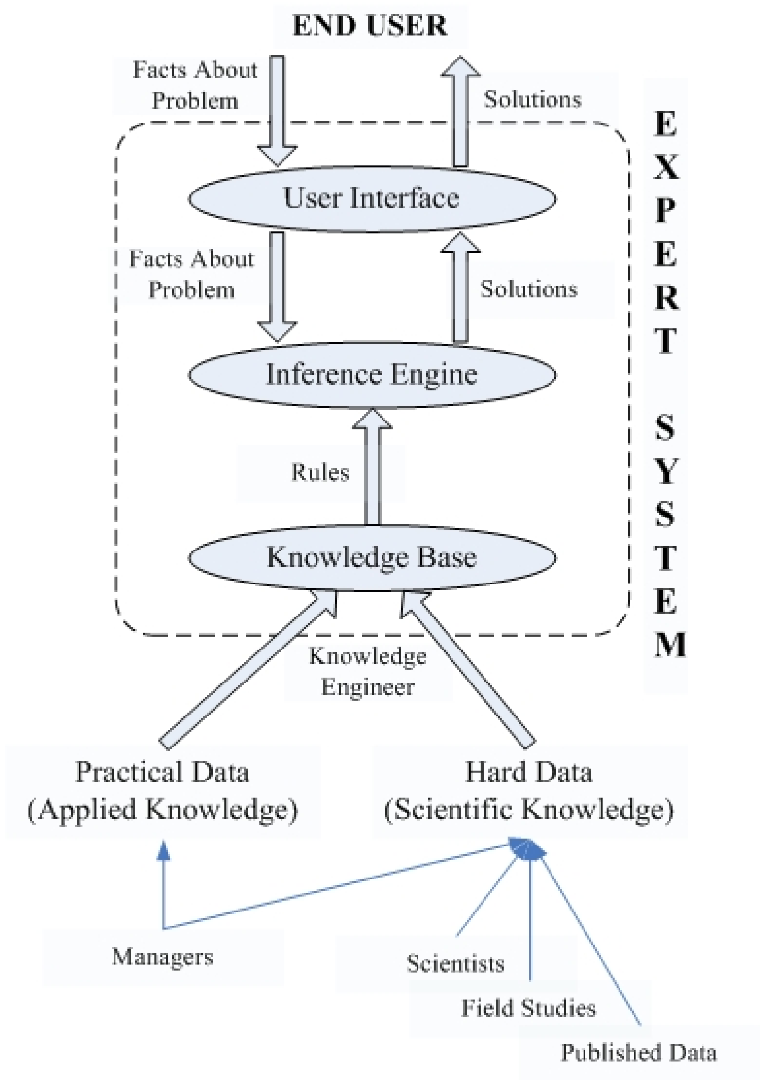

Figure 2-9: Berkes' Expert System Structure.
(Berkes *et al.*, 2001)

Berkes' (2001) structure illustrates how an Expert System should operate as well as key relations among knowledge base, external data modules, inference engine and user interface. In addition, roles of knowledge engineers and users are highlighted in the development process and system operation, respectively. In this respect, Berkes (2001) proposes the development of the Knowledge Base by using both practical and hard data. These data come from a number of sources, such as experts (managers and scientists), published material, field studies and etc. Data is used to create information which is ultimately represented in forms of rules within the Knowledge Base. The interface between user and Knowledge Base operates through the Inference Engine (IE). IE is the operational module, which process data/facts provided by the user using the rules contained in the

Knowledge Base. Outcomes from this process are named solutions or recommendations and aim at supporting decision-making.

The review of ES and their structures highlighted a number of additional concepts. Giarratano and Riley (1998) describe eight general concepts commonly used to develop ES applications:

- Languages: commands written in a specific syntax. Must be associated with the inference engine to execute the statements;
- Tool: a language and an utility program to facilitate development, debugging and delivery;
- Shell: a special propose tool designed for certain types of applications in which the user must supply only the knowledge base;
- User Interface: mechanism in which user and the ES tool can communicate;
- Explanation Facility: component that explain the reasoning used to achieve solutions;
- Working Memory: global data base of facts;
- Agenda: prioritized list of rules from the working memory; and
- Knowledge Acquisition Facility (or rule induction): automatic way to acquire knowledge by creating new rules from examples.

2.3.2.5 Expert Systems Applications

Expert Systems have been under development and use since the seventies. Although technologies and requirements have considerably changed over the period of forty years, an ES application still aims at providing expert knowledge to decision-makers in order to facilitate and improve decision processes.

In the seventies, the systems DENTRAL, MYCIN, DIPMETER, PROSPECTOR and XCON/R1 become very popular due to potential impacts in savings and decision-making agility. For instance, PROSPECTOR was used to find a mineral deposit that worth at the time about U$ 100 million and the XCON/R1 helped Digital Equipment Corporation to save millions of dollars a year, reducing the time to configure the orders and improving its accuracy.

Currently, agriculture research has invested in developing ES (e.g. AGREX) to help farmers to make better decision in the areas of fertilizer application, crop protection, irrigation scheduling, and diagnosis of diseases in paddy and post harvest technology of fruits and vegetables. Applications in medicine continue to be developed as a pioneer field. A specific example would be the PXDES systems, which detects pneumoconiosis, a lung disease through X-rays. This particular system incorporates an inference engine to examine the shadows on the X-ray. The shadows are used to determine the type and the degree of pneumoconiosis so medical decision can be facilitated. Finally, Steadman and Pell (1995) proposed an ES for helping manufacturing processes. Steadman and Pell's system provide tools to support complex engineering designs such as the injection molding of plastic parts.

2.4 Conclusive Topics

This comprehensive literature review has found Emergency Management to be a complex topic, in which a number of concepts are interrelated. We initially defined the EM field by presenting basic management structures used during disaster situations as well as related concepts. Systems such as CIMS or ICS support organisational arrangements, co-ordinate response and recovery, distribute resources, enforce information sharing process and etc in order to ultimately facilitate the management of emergencies in spite to specific circumstances faced.

Nevertheless, decision-making processes at individual, departmental, corporative and inter-organisational levels are still unclear. A review of Decision-making theory has led us to a better understanding of models, paradigms, reasoning structures etc used by human beings when making decisions in numerous fields. A specific focus was given to decision-making models during emergency events. Some authors (Dreyfus, 1981; Sweller, 1988) indicate that under pressure and uncertainty typically faced during disasters, decision makers tend to use the Naturalistic Decision Model. This model regards to a three stage process (known as Situation Awareness, Sense Making and Planning), in which decision makers compare present situations with previous experiences under rational paradigms. Improvisation is used when patterns are not found in existing memory structures.

The process described above involves a great deal of knowledge, memory and expertise. Pattern matching requires well structured memory for identification of prototypical situations and improvisation is performed using comprehensive knowledge/expertise. In this respect, information systems such as Decision Support Systems and Expert Systems help to represent and manage knowledge; therefore, facilitate decision-making. Nevertheless, knowledge generation and representation is considered to be a complex task due to high levels of cognitiveness involved in decision-making. Successful applications have already been reported in the literature by Mendonça and Mendonça *et al.* (2001), Mendonça (2005), Mendonça *et al.* (2006) and Wallace (2007).

Finally, it is believed that this comprehensive background can support the proposal and design of the DRRT. The case of roading organisations is considered according to the objectives defined for this thesis. Thus, we initially envisaged the need to specifically study decision-making processes applied by roading personnel during emergencies. So emergency exercises were observed as this particular approach can objectively simulates real instances and common decision-making processes faced by emergency managers. A specific observation technique and a series of case studies will be used to collect and process data about decision-making processes. The next chapter reports on these developments and experiences using New Zealand Roading Organisations as case studies.

3 UNDERSTANDING THE ORGANISATIONAL CONTEXT OF EMERGENCY MANAGEMENT

Extreme events present responding organisations with complex and unprecedented situations, which may generate catastrophic losses and disruptions for communities. In a crises or emergency there is an immediate risk to life, health, property and environment (Vedder, 1990; Fink, 1986; Berroggi and Wallace, 1995). Thus, organisations have to quickly respond to observed and changing conditions. These events are usually different of what personnel are used in dealing with on a daily basis, under business-as-usual circumstances (Fredholm, 1999).

However, there is limited understanding of how organisations make decisions during extreme events. Some recent studies provide empirical evidence that decision makers are impaired by existing complexities in real situations (Zografos *et al.*, 2000; Mendonça *et al.,* 2001; Mendonça, 2005; Sinha, 2005; Mendonça *et al.*, 2006; Mendonça and Wallace, 2007). Such studies also indicate through anecdotal evidence that decision makers use their own experience and common sense in order to respond to events.

This chapter presents a method used to observe and collect data during emergency exercises and real events. The method aims at studying organisational emergency management at deeper levels by incorporating a balanced representation of emergency realities. Such approach targeted to acquire useful information about organisations' decision-making processes, which was further used to analyse the organisational context where extreme events decision-making occurs. Furthermore, experiences can be achieved through gradually becoming involved and immersed in the organisation's context.

The first section presents the observation and analysis methods. Building upon this proposed framework a series of three emergency exercises and two real events were observed and are reported in the second section. The final section is dedicated in presenting the findings from the case study experiences in a broad context.

3.1 Observation Framework

This section describes the observation framework and the analysis method proposed to collect and process data from real and simulated emergency events, respectively. The framework is focused on four extreme events decision-making domains: physical, information, cognitive and social.

3.1.1 Observation Method

A five-step observation method was developed, taking advantage of the fact that emergency exercises are routinely practised in New Zealand. This method aimed at identifying and observing emergency training endeavours accordingly to the following process:

- **Step 1:** Search for appropriate upcoming emergency exercises;
- **Step 2:** Once an exercise is identified, contact the organisations responsible for organising the exercise in order to check if it is possible to take part as observers;
- **Step 3:** If participation is authorised, get familiar with the dynamics, participating organisations, objectives, major players, scenario and injects[3];
- **Step 4:** Arrange consumables/processes needed to conduct the exercise observation, focusing on the three steps described in Table 3-1; and
- **Step 5:** Report the experience to fellow researchers in order to exchange alternative points of view

Although the process seems fairly simple, it incorporates two complex realities. The first of these is the issue of commercial sensitivity and getting organisational consent for the intended observation and analysis. The researcher always guaranteed anonymity and name suppression in order to facilitate the authorisation (refer to Appendix A for ethics committee approval). The second complication involved the technical challenges of properly observing and capturing data/information for further analyses. An adaptation of the Defence Command and Control Research Program (CCRP) model (Cheah *et al.*, 2000) was used to conduct the observation and

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[3] Refer to injections of specific information about the emergency scenario under simulation.

collect data as required in Step 4. The CCRP method is further explored in the next sub-section along with the analysis process.

Finally, the observation of real events occurred in a flexible manner as they cannot be obviously predicted. In this context, the research team was required to maintain up to date key contacts with NZTA, consultant and contractor in order to quickly obtain permission to go to the field. For safety reasons, researchers were only authorised to observe real events either at office headquarters or properly accompanied by experienced field professionals.

3.1.2 Analysis Method

The general analysis method is described in this sub-section. It aims at the understanding of the four decision-making domains. The method focuses on assessing collected data under three key elements of decision-making (known as situation awareness, information sharing, and expertise/experience). Each of these elements are scrutinised according to the research steps, observation activities and expected outcomes illustrated in Table 3-1.

Table 3-1: Observation Activities and Expected Analyses of Emergency Exercises.

Step		Observation Activities	Expected Outcomes
1	Knowledge Elicitation	Observation of the decision-making process during real and simulated extreme events; tracing of decision-making stories.	- Comprehensive understanding of the real or simulated event scenario; and - Qualitative assessment of the tangible/intangible vulnerabilities affecting decision-making.
2		Debriefs and in-depth interviews with experts in the subject matter following real and simulated events.	Identification of the cognitive elements that underlie decision-making.
3	Analysis and Knowledge Representation	Extracting meaning from the acquired data and information and displaying the results.	Assessment of the strengths and weaknesses within the decision-making processes.

Each of the previously mentioned decision-making domains is described as follows in order to support data analyses. They have been adapted from traditional definitions to specifically suit the case of roading organisations.

- **Physical domain***:* this is the tangible real world where physical and human resources are moved through time and space to perform the range of operations required to respond an evolving extreme event;
- **Information domain**: the abstract space, in which data exists and is collected, created, processed, manipulated, and shared in the form of information. This ultimately represents the flow of information content, i.e. the link between reality of the physical domain and human perceptions;
- **Cognitive domain**: the mind of the decision-makers, where the individual and organisational collective consciousnesses exist. The decision makers' knowledge, capabilities, techniques, and procedures are stored here; and
- **Social domain**: where humans interact, exchange information and form a shared awareness and understanding, as well as make collaborative decisions. This domain encompasses the intangibles of culture, values, attitudes, beliefs and leadership.

3.2 Case Studies

This section summarises three simulation exercises (Table 3-2) and two real events (Table 3-3) involving SHO. All cases were observed in New Zealand since 2007.

The exercise observations comprise a major earthquake (Icarus exercise), a tropical cyclone (Marconi exercise) and a major volcano eruption in the Auckland area (Ruamouko exercise). The observed sample has included two types of exercise (tabletop and functional) and a significant variety of levels of organisational involvement (national, regional and single organisation). Only one observed exercise was classified as a table-top exercise (Marconi exercise) while all the others have been identified as functional exercises.

Due to resource limitations (mainly human resources), it was only possible to directly observe the consultants and contractors actions and decision-making procedures in the Icarus exercise. For all other exercises, only the activities at the New Zealand Transport Agency (formerly known as

Transit New Zealand) were observed. From all cases, consistent decision-making data was collected.

Table 3-2: Observed Emergency Exercises.

Name Date Location	Simulated Event	Exercise Typology	Aim	Observed Organisations
Marconi Exercise 8th June 2007 Auckland	Tropical cyclone causing significant damage and flooding in the Auckland Region	Distributed tabletop exercise organised by the Auckland Engineering Lifelines Group	Lifeline utility co-ordination processes in the Group EOC with focus to information transfer	NZTA Northcote Traffic Management Centre (ATTOMS Centre) Auckland
Icarus Exercise 22nd November 2007 Wellington	Major earthquake in Wellington	Functional exercise as part of the NZTA scheduled annual training	Train staff in their roles within EOC (Emergency Operations Centre); practice allocation and communication between organisations; test aerial reconnaissance arrangements between NZTA and Greater Wellington Regional Council (GWRC)	NZTA Wellington Regional Office, Consultants one contractor and the GWRC
Ruamouko Exercise 13th March 2008 Auckland	Volcanic eruption in Auckland	Tier 4 national-level functional exercise in accordance with the MCDEM National Exercise Programme (joint local government and central government exercise, Auckland CDEM Group, MCDEM, DPMC)	Test New Zealand's all-of-nation arrangements for responding to a major disaster with particular focus on roles and responsibilities, arrangements and connections between, local, regional, national and international agencies	NZTA National Office in Wellington, GEOC Auckland, GEOC Wellington, ATTOMS Centre, Waitakere EOC

Complimentarily, two real events were observed. The Mount Ruapehu (Tongariro National Park) eruption was observed on site by a single researcher as well as monitored by two others from their respective offices at the University of Canterbury in Christchurch. The field observation was conducted solo as no major hazards were associated with the events due to its small scale. Furthermore, the management activities conducted by a national consultant were observed over a day during the 2008 Storm events, which affected the south island of New Zealand.

Table 3-3: Observed Real Emergency Events.

Name Date Location	Summary Event Description	Organisations Observed
Mount Ruapehu Volcanic Eruption 25th of September 2007	A 2.9 Earthquake occurred on the night of the 25th September that triggered a number of response actions from NZ Police and a local contractor. The response included the evacuation of sixty people from Aorangi and Ruapehu huts, closing ski fields on the 26th September and assessing damage at State Highways surrounding the Tongariro National Park on the night of the event. Road damage was not reported and an injured climber was the only direct victim of the event.	National contractor (on site observation)
The 2008 Storm Events 31st of July 2008	During late July 2008, a severe weather front arrived in New Zealand. Both north and south islands were affected by heavy rain, which created flooding and landslides. From the 28-30th July, four researchers monitored the event's development. On site observation at the consultant's office took place on the 31st July when the storms badly affected the South Island's state highway network. Major damage observed included flooding in both north and south of Christchurch and a major landslide south of the Kaikoura Peninsula on SH1.	National consultant (office observation)

The following sub-sections describe in detail all observations conducted as well as the initial findings achieved from it. They include all research activities undertaken before the observation (e.g. contacting organisations, engaging with staff, organising research material, arranging data collection tools) as well as specific details about the scenario or event. Finally, general findings about responses performed, such as common management processes applied, impact assessment, pending issues on response and so on are individually discussed for observations.

Overall, all observations contributed towards the understanding of organisational emergency management in New Zealand and data collected were suitable for analyses. Thus, the observations consistently supported in-depth analyses of structured roading organisations emergency management operations.

3.2.1 *Marconi Exercise*

On the morning of Friday 8th June 2007, the Auckland Region exercised coordination and communication between lifeline utilities and Civil Defence Emergency Management (CDEM) centres. The exercise focused on the response phase of a major emergency, simulated via a distributed tabletop exercise. The exercise was led by the Auckland Engineering Lifelines Group (AELG) representing Auckland transport, water, energy and telecommunication utilities in conjunction with the Auckland CDEM Group.

The Emergency Operation Centres (EOC) at Auckland, North Shore, Waitakere and Manukau cities, the CDEM group EOC team and the lifeline utility coordinators took part in the exercise together with 24 lifeline utility organisations across many sectors. The transportation sector was represented by NZTA, On Track (the regional railways corporation), Air New Zealand and Auckland International Airport.

The aim of the exercise was to review and improve the lifeline utility coordination response processes. In this context, specific objectives were defined as follows:

- To review lifeline utility co-ordination processes in the group EOC through escalating levels of emergency (culminating in a group declaration of civil defence emergency);
- To assess the lifeline utility interface with the group EOC with a focus on communication; and
- To perform information transfer.

Beyond the abovementioned objectives, lifelines utilities were free to test their own plans, processes and procedures during the exercise.

Scenario

The scenario was an extreme weather event (tropical cyclone) causing significant damage and flooding in the Auckland Region. For the transport sector the damage scenario involved: a) high wind gusts (up to 170km/h) wit potential hazards for vehicles crossing Auckland Harbour Bridge; b) heavy rainfall; c) heavy sea swells and inundation; and d) major flooding on the State Highways and on the main arterial routes. The scenario complimentarily included a widespread and prolonged power outage with uncertain times for service restoration, possible fuel shortage and telecommunication disruptions.

The seriousness of the scenario induced other effects such as main road closures, including the Auckland harbour bridge, traffic signal failures and subsequent gridlock and traffic accidents. It was also simulated the inability of emergency services to reach affected sites or hospitals, evacuation needs, and the dependency on the telecommunications and electricity sectors.

Roading utilities were assessed within their responsibilities such as liaison with the Police to control the roads, use of contractors to assist in traffic control and restoration of priority routes. At minor importance, they were required to assist councils to manage evacuation, to support emergency services and to arrange for aerial reconnaissance if needed.

Relevant Emergency Management Procedures Observed during Marconi Exercise

Lifeline Utility Response and Recovery Protocols (AELG, 2006) outlines recommendations for communication and information transfer between the lifeline utilities and the Emergency Operations Centre Group (thereafter referred as Group EOC). Utilities are expected to communicate directly with each local Emergency Operations Centre (also known as local EOC) to manage specific localised emergencies.

In an event of regional scale, the coordination of the lifeline utilities will occur at a regional level via a Lifeline Utility Coordinator, who belongs to the group EOC. Such coordination was exercised during the Marconi exercise when local authorities continued to report locally with relevant local EOCs. In this backdrop, the CDEM group public information management shall control media and public communication. Moreover, the NZTA makes use of its emergency procedures manual for region 2 (TNZ, 2000) and the guidelines from the Auckland Engineering Lifeline Group Project 5

(AELG 2004, AELG 2005), which identifies priority routes for response and recovery activities in the Auckland region.

Activities Observed at New Zealand Transport Agency

The New Zealand Transport Agency (NZTA) used the emergency management room in the Northcote Traffic Management Centre (ATTOMS Centre). The Centre is also used to monitor traffic 24 hours/7 days a week in the Auckland Metropolitan area. Three participants from NZTA took part in the exercise plus the ATTOMS centre manager.

The exercise had a "warm start" in which it was assumed that the initial notifications and activation of EOCs had already been carried out after a MetService weather warning was issued in the day before. This meant that staff were on standby and the EOC group was already activated. Exercise injects were sent via e-mail as attached files in "word document" format. Such injects were originated from the Lifelines Utility Coordinator to all the lifelines utilities participating in the exercise. The injects comprised weather warnings and updates on the development or progress of the scenario. Three types of injects were received before the formal start of the exercise: 1) weather warnings; 2) radio station news; and 3) Auckland group EOC initial general situation report.

After the "warm start", NZTA staff mostly focused on impact assessment/communication and identification of pending issues and reporting back needs/implications. The following describe the outcomes of these activities.

NZTA Impact assessment and communication

The impact assessment was made exclusively on the basis of injects that were received from the lifelines utility coordinator as NZTA road maintenance contractors did not participate in the exercise. In order to facilitate discussions about possible consequences to network operations and possible actions to be undertaken, key information was summarised on a white board. The damage and disruption highlighted in the first three injects received as well as possible response actions to be taken were colour coded by NZTA staff on a laminated map.

Subsequently NZTA, together with other lifelines utilities, were requested to state their current situation and report to the lifeline utility coordinator. Thus, the NZTA personnel produced a report comprising:

- The overview of the scale and extent of event and the identified and likely future impact on the road network;
- Major disruptions experienced including location and number of customers affected in each location and estimated restoration times;
- Priority areas for response actions;
- Public information and precautions to be promulgated;
- Specific requests for support and information enquires;
- Additional critical pending issues; and
- Action required by Group EOC.

Identification of Pending Issues Arising from the Scenario and Needs Report and Implications

Following an external request from the lifeline utility coordinator, NZTA had to analyse the interdependencies among lifelines utilities. It has been done by considering a detailed report provided by the electricity sector. This intended to encourage organisations to analyse pending issues arising from a possible electricity shortage. Furthermore, each lifeline utility sent a report to all other participants to share information. Nonetheless, NZTA did not take any formal action to summarise the information received from the other lifelines utilities.

In specific for the electricity sector report, lifelines utilities were required to deal with three main issues: i) to test of alternative communications; ii) to identify the services dependent on fuel and fuel stocks assured for the next 3-5 days (contacting the fuel supplier directly to ascertain this, if necessary); and iii) to use the priority sites lists and maps provided in AELG (2005) as priorities for restoration.

Regarding the test of alternative communication, contacts via radio were attempted with the NZTA regional office in Auckland and with one contractor. The initial attempt was unsuccessful. Communications via fax were also tested. The main road closures resulting after the damage scenario were sketched on a map showing that the highway network in the Auckland region.

Fuel issues were discussed and NZTA stated that "contractors will need diesel by the 10^{th} June". The fuel stocks assured for the next 3-5 days were identified on a map, but fuel suppliers were not contacted in order to confirm the accuracy of the information.

Finally, priority sites lists and maps were assumed to be the same previously identified by Auckland Lifeline Organisations Group (AELG 2004, AELG 2005). Priority routes for Auckland City as well as a different set of geographic supporting information were available at the EOC, but seldom consulted by NZTA staff.

3.2.2 Icarus Exercise

On the morning of the 22^{nd} November 2007, the NZTA Wellington Regional Office, in conjunction with its consultants and contractors, exercised its emergency response arrangements. The exercise was part of the scheduled annual training organised by the NZTA Wellington Regional Office and involved two consultancy companies (MWH and OPUS), one contractor (Fulton Hogan) and the Greater Wellington Regional Council (GWRC).

One of the aims of the exercise was to train staff in their respective roles. The exercise was also used to test the practicality of the aerial reconnaissance arrangements that have been developed through a Memorandum of Understanding (MoU) between the NZTA and the GWRC.

The following presents in detail, the observation conducted at the Fulton Hogan Emergency Operations Centre (EOC). Furthermore, the observation at both NZTA and lifeline coordinator sites are discussed. Findings about decision-making activities were presented and communication issues identified after observing the exercise Icarus.

Scenario

The exercise was based on the 2006 Capital Quake scenario. It comprised a major rupture in Wellington's fault creating major damage at Wellington city and region. The NZTA modified the scenario in order to meet the specific objectives set up for the exercise. These modifications focused on preparedness and decision-making to reopen State Highway 1 (SH 1) north of Wellington. Specific exercise objectives were:

- To practice EOC operations and role delegation;
- To interpret reconnaissance information acquired by Fulton Hogan field staff and aerial photographs; and
- To train and practice interactions between organisations and the Lifeline Utility Coordinator.

A research team member observed Fulton Hogan's EOC on the day of the exercise. The aim was to obtain data about decision-making and communication performed during the exercise. The simulation ran from 9.00am to 12.30pm and included the various small events as listed by the exercise planning document made available to organising members previously the simulation:

- Bridge over motorway at Johnsonville – holes in the road on both sides of the bridge – soil collapsing;
- Rail bridge over motorway at bottom of Ngauranga Gorge – smoke coming out of tunnels, East (South) bound lanes blocked;
- Aotea Quay bridge onto Hutt Road – span fallen down with obvious displacement of bridge both ways;
- Motorway over rail yards – one span on catchers and displacement to both north and south bound lanes;

- Motorway off-ramp by James Cook hotel blocked with debris by a fallen building;
- North end of Terrace Tunnel – slips cover north bound lane;
- Portal at eastern end of Mount Vic Tunnel – blocked by a landslide;
- Southbound section of road between Pukerua Bay and Plimmerton – slips; and
- Between Pukerua Bay and Fisherman's Table – massive slips/blockages (and a passenger train half visible within one of the slips).

Although the exercise's primary goal was to reopen SH 1, conflicting information about SH 58 was also given in order to create more challenging decision-making problems. Furthermore, it was expected that organisations would improvise and create injects in order to test their own procedures and to train their respective emergency response teams. Damage and information about the road network was provided to participants through a series of standard injects.

Activities at the Fulton Hogan Emergency Operations Centre

The Fulton Hogan Emergency Operations Centre (EOC) was set up at the Wellington area office (Marine Parade, Petone). The observation process can be divided into three different phases: 1) Pre-exercise, 2) Exercise observation and 3) Post-exercise. The description of each phase is presented as follows:

1) Pre-exercise: The room was initially arranged to reflect possible effects from an earthquake. This was followed by a quick introduction presenting the scenario, exercise rules, objectives and etc. The Fulton Hogan's manager clarified his role during the exercise and the expectations of FH's team in terms of response and emergency management.

Available resources were discussed at this stage (e.g. building facilities, communication infrastructure) in order to plan response strategies. The following consumables were made available for FH personnel during the exercise:

- A single room commonly used for meetings in the company;

- A Radio Transmitter (RT) to communicate with other organisations;
- A single landline phone;
- 2 white boards fixed onto the walls;
- A desktop computer;
- A box containing an emergency kit including safe vests, gloves, buckets, non perishable food, torches, gas torches, blankets, respirators and etc;
- 5 tables and a carrel;
- A flip chart;
- A portable white board;
- Maps for the Wellington Area including a map with state highways, urban areas etc. and a map from Civil Defence (CD) showing priority routes and CD Centres;
- Emergency response forms;
- A box containing a great range of office consumables;

2) Exercise observation: The participants had to arrange the EOC room after the formal start of the exercise at 9.00am. In addition to taking notes about actions and discussions, pictures were taken, discussions recorded and a survey form completed as part of the observation of the exercise. The data collected comprises 45 pictures, a three page long survey and approximately 36 minutes of audio recordings. A detailed timeline presenting injects, decision-making, communication and discussions on the morning of the exercise was produced. Refer to Dantas *et al.* (2010b) for full details.

While every effort was made to collect all available data during the exercises, it is inevitable to miss response actions, decisions or discussions due to the complex and extremely dynamic nature of emergency exercises. Overall, the observation focused on general aspects of decision-making and communication performed during emergency events and how they could be improved.

3) Post-exercise: A hot debrief was conducted immediately after the exercise was officially finished. Participants were asked to complete a survey. The team then discussed response strengths and weaknesses identified during the exercise. The following presents a non exhaustive list of issues raised during the hot debrief:

- Stress management (especially when injured staff are involved);
- Emergency Depot Roles clarification (EOC Manager, Information and Communication Manager, Road Clearing Operations Manager and Logistics and Staff Requirements Manager);
- Information sharing and support from other organisations;
- The use of NZTA Emergency Response Plan, Fulton Hogan's procedures and Role Description laminated sheets;
- EOC Room layout;
- EOC equipment (e.g. desks, desktop computer, printer, RT);
- EOC location at Fulton Hogan area office at Marine Parade, Petone, Wellington;
- Power availability during real events and generators; and
- Emergency box items.

3.2.3 Ruamouko Exercise

On the morning of the 13th March 2008, various lifelines organisations, and Civil Defence groups simulated a major volcanic eruption in the Auckland region. The exercise was organised as a Tier 4 national-level exercise (a joint local government and central government exercise) in accordance with the CDEM National Exercise Programme. It aimed to test New Zealand's all-of-nation arrangements for responding to a major disaster. A particular focus was given on roles and responsibilities between local, regional, a national and international agencies.

The exercise included features typical of a full scale exercise (e.g. simulation, resource assessment and deployment and damage assessment operations). For the NZTA National office, the challenge was how to cope with the massive evacuation planned for residents within the 5 Km radius blast zone. It was expected that the evacuation would cause significant congestion on motorways and SH 1 to Hamilton as well as SH 2 to the east coast. Another important issue raised by the exercise was staff safety for both NZTA and its suppliers, given the potential severity of the event.

Scenario

The scenario comprised a volcanic eruption located at the inner Manukau harbour. It was expected to severely damage land transport and to severely affect the north island.

The exercise commenced with the identification of precursor activity in the form of seismicity in the Auckland region during November 2007. In early 2008, unusual and sustained seismicity in the Auckland region prompted further attention until it was clear that a volcanic eruption was becoming imminent due to increasing seismic activity. The scenario also simulated earthquakes with intensity equal to Mercalli Intensity 6-7 in last 24-48 hours before the actual eruption, which included:

- Violent explosions caused by magma coming into contact with water; sound/pressure shock waves and complete devastation 1-3 km from vent;
- Extremely violent base surge phenomenon with turbulent ground-hugging flows of ash/gas with a speed of 50-300 km/h;
- Ash fall;
- Fountains in the vent area only lasting from 1 week to several months;
- Lava flows crushing and burning everything within 1-10 km from vent and lasting from several weeks to months;
- Risk of widespread fire from hot ash, lava, or disrupted gas supply lines within 1-10 km from vent; and
- Asphyxiating gases (CO, CO_2, HF, SO_2) accompanying lava flows within 1-5km from vent.

Physical impacts included damage to infrastructure and transportation utilities (including roads, ports, and airports) and disruption to critical services, such as electricity, gas, fuel, telecommunications and water. The damage from the eruption severely affected the ability of the remainder of the North Island to function and provide support to refugees.

Road controlling authorities were asked to understand and simulate the reaction for the city population during the volcanic eruption. It aims at predicting the level of panic, trips direction and the main purposes of trips. Self evacuation was considered the primary means, including 60% of residents within the 5 Km radius blast zone. As a result Civil Defence was responsible to moved 40% of affected people and encourage 60% to self evacuate. This created great pressure on the NZTA to manage the motorway and SH 1 to Hamilton as well as SH 2 to the east. The event escalated considerably as it coincided with the normal evening rush hour peak flow.

Observed activities

Researchers were distributed throughout five different locations (NZTA national office in Wellington, group emergency operations centre, GEOC Auckland, NZTA Northcote traffic management, national GEOC Wellington and evacuation coordinator support at Waitakere EOC). Such great number of researchers allowed vast data collection and a very comprehensive observation process.

It was observed that participating organisations had substantially different levels of awareness on initial situations (e.g. impact assessment, damage identification and vulnerabilities). Upon the introduction of initial injects, organisations faced a common issue, which was to predict how the volcanic eruption could affect the immediate and extended surrounding areas. It was also questioned whether these impacts aligned with assumptions made during previous planning. For instance, the NZTA National office showed very limited knowledge about affected area/assets, personnel, volcanic explosion consequences, and how traffic would behaviour and traffic management should change in the face of the chaos. At the regional level, the NZTA relied on previous knowledge about the network, but ignored the fact that evacuation patterns could be significantly different to those observed during other types of events. The Group Emergency Operations Centre (GEOC) in Auckland had access to a considerable amount of scientific information about the implications of the eruption. However, had a limited understanding to where to evacuate people and had different views on how traffic would be affected.

Situation awareness had considerable influence on how participants understood and proactively managed vulnerabilities. For instance, the NZTA National Office did not take an active role during the exercise. The participating personnel were reluctant to get involved and decided to wait for requests from the NZTA Regional Office. Overall, it was observed that participating organisations were waiting for information rather than proactively seeking it. One exception was the Bay of Plenty (BOP) regional council that proactively engaged in seeking information on estimated arrival numbers and responding by directing the appropriate amount of evacuees to their respective welfare centres. The BOP was also accountable in back feeding this information into other organisation in order to facilitate their decision-making process.

The different perceptions of the initial situation were mostly due to difficulties in assimilating incoming information. Most participating organisations relied heavily on email communication, which would, in principle allow them to share text documents, maps and other various data about the event. Due to the magnitude of the event, participating organisations were swamped with very large and varied communication attempts. These eventually did not materialise into useful and reliable information that could support decision-making. On the contrary, it was often observed that staff would spend significant time dealing with communication problems (e.g. email sizes, spam filters and delays).

Such difficulties were clearly shown by the way the NZTA processed information. At the national level, staff decided to use as little information technology as they could, with the exception of email messages. At the regional level spreadsheets for logging phone calls and other acquired information were produced during the exercise. Finally, regional staff recognised that they should not rely only on emails and phones as those could be unavailable in a real event. Nevertheless, no ideas on how to overcome these issues were considered.

Good adaptation was shown as many participating organisations managed to adjust as the exercise progressed. On one side of the spectrum, the expansion of the eruption affected area prompted the NZTA regional office to quickly reorganise the traffic management arrangements. On the other side of the spectrum, the NZTA national office showed poor adaptive capability to deal with new situations. The national office staff also showed limited communication actions as updated information about the event was seldom transferred to regional and local NZTA offices.

3.2.4 Mount Ruapehu Volcanic Eruption

On the 25th September 2007, the Mount Ruapehu volcano erupted in the New Zealand's north island. According to the Ministry of Civil Defence and Emergency Management, the eruption occurred at 8:20pm without any warning and lasted for about ten minutes. As a precaution, the ski fields were closed the following day and sixty people from Aorangi and Ruapehu huts were evacuated. The adjacent state highway was also closed until possible damage was assessed. The eruption was accompanied by magnitude 2.9 ground shaking on the Richter Scale that lasted seven minutes. An injured climber was the only direct victim from the event.

The eruption prompted regional Police, Civil Defence and NZTA's regional contractors to activate emergency response procedures. The event received attention from international, national, regional and local media as well from government agencies.

The eruption caused concern for the local population, who criticised authorities for a lack of communication as rumours about a failure in the warning system were circulated. However, the Conservation Department Tongariro acting manager said that the alarm system had worked and the police area commander advised that appropriate response steps were taken to communicate those in the region in accordance with the emergency response plan. Nonetheless, the confirmed failure of the cell-phone text message alert occurred because the event created a magnitude 2.9 earthquake, while the alert threshold is a magnitude 3.4. Ruapehu's ski fields were expected to reopen on the day after the event, but they were only re-opened three days after the eruption. Many tourists complained about the ski field closures as it happened in the middle of the busy school holiday period. No property damage was reported and roads were closed for damage assessment until 11 pm on the night of the event. The mountain's extreme unpredictability and potential for further eruptions highlighted the importance of having a good warning system in the region and well defined response procedures and plans.

Contractor's Experience

An interview was conducted at the Work Infrastructure's office at Taumarunui on the 26th September 2007. Information collected during the interview confirmed that after the Mount Ruapehu eruption, the contractor was alerted via the after-hours emergency system (around 9:40 pm). The decision to close the state highway was made at that time and road blocks and temporary signage were set up while assessing the road conditions. Road blocks were located at Ohakune, Manunui, Waiouru and Rangipo. Also, a small section of the SH was closed, but drivers were allowed to pass with caution.

Eight light trucks with road management gear (signs, barriers, flashing lights) and 14 people were used to set up the road blocks. Gears were located at local depots located at Taumarunui, Raetihi and Turangi. Roads were re-opened at approximately 11:30pm on the same night of the event as no damage was found. Two staff were left at Turangi to monitor the situation over night.

Road assessment was conducted by driving in the network and visually assessing the condition of pavements, culverts, signage and etc. Occasional assessments were performed by stopping for a visual analysis at critical points (mainly bridges) to check for possible damage. Costs involved in the response for Ruapehu's Eruption (mainly petrol and wages) were claimed from the NZTA.

New Zealand Police's Experience

An interview with the local police inspector was conducted at Taumarunui on the 29th September 2007. According to the police inspector, after the volcanic eruption the New Zealand Police received a 111 phone call from a ski operator. It was noticed that the Eruption Detection System (EDS) did not work as the earthquake event accompanying the volcanic eruption was of the magnitude 2.9. The EDS system is set up to be triggered by a magnitude 3.4 event. Recommendations were made in order to lower the alarm trigging threshold.

The policeman decided to close roads in the region of Mount Ruapehu in face of his 17 years of experience in the area and on lessons identified after the 1995 Mount Ruapehu volcanic eruption. This indicates the use of experience and previous knowledge like in a naturalistic decision-making process. Although appropriated for such cases, this process has to be carefully considered as emergency events are unique. Hence, 1995's experiences can be definitely applicable, but it needs to be re-assessed in face of new infrastructures, communication technologies, public expectations and etc.

The situation was managed using the principles from the Coordinated Incident Management System (CIMS). According to the standard procedures of CIMS, the Communication Centre of Taumarunui Police contacted the local contractor. The police inspector expressed concern about the decision process and effectiveness applied by the contractor. It was argued that road blockages could be quickly pt in place as the contractor has resources scattered in the affected area. While waiting for the contractors, the police staff drove along the closed roads to check its condition. The NZTA and the consultant were not contacted by the Police, which fully coordinated the response with the contractor.

After the roads were closed and the contractor arrived in the area, the police inspector travelled to the Emergency Operation Centre established at Whakakapa, in the Department of Conservation's

(DoC) Office. A DoC staff member was assigned to the role of incident controller and Local volunteers were appointed to different roles required by the CIMS structure.

The decisions taken on the night of the event comprised the evacuation of 60 people from Iwikau Village to Hotel Chateaux. As the situation became clearer, an alternative option to return to their accommodations was immediately granted. Roads were closed for assessment until the contractor had confirmed their safety condition. The final decision concerning the event was to close the ski fields until the situation was under control.

GNS Science monitored and evaluated the volcano activity regularly until a final decision could be made about re-opening the ski fields. On the day after the event, two meetings a day (scheduled for 4.30pm and 6.00pm) were hosted by GNS until the situation could be considered as completely safe.

3.2.5 The 2008 Storm Events

During late July 2008, a series of storm events affected New Zealand. The South Island was badly affected and in particular a Civil Defence Emergency was declared in the Marlborough District Council region.

Dozens of people were evacuated from their homes and a camping ground was set up in Picton due to the flooding. Swollen streams were made worse by a high tide and sandbags were used to try and kept rising water from houses. In Nelson, a major water pipeline was damaged by falling trees and authorities asked residents to minimise water consumption. About a dozen residents from Sefton, north of Christchurch, were also evacuated because of the events and were moved to a local school hall.

Flooding forced the closure of State Highway 1 between Blenheim and Kaikoura. Emergency services warned about flooding dangers in many parts of Canterbury and Marlborough, including Christchurch city. However, few roads in Christchurch and the Waimakariri area experienced surface flooding. The situation was worsened by extreme winds which were lifting roof tiles and scattering branches and other debris throughout neighbourhoods.

The decision process relevant to the management of the State Highway network in the South Island was observed at Opus International Consultants' office in Christchurch. The observation lasted for approximately seven hours on the 31st of July 2008.

Consultants mostly liaised with contractors and the NZTA. A very comprehensive information sharing process was observed between consultants and contractors while NZTA oversaw the situation. The consultant's staff have shown deep understanding of how to conduct the response. It was seldom observed hesitation on decision-making regardless the extent of the situation and external pressure.

The only limitation identified refers to the lack of a secondary response team. For instance, the main manager was in charge since early in the morning (4.00am) and had no one to replace him until the research left the organisation (5.00pm). Although its criticality, the same manager did mention in a latter instance that the organisation did have spare staff to take over the situation if needed. It was also mentioned that contingency plans such as a secondary office location exists in case of the major building cannot be accessed due to limited transportation or collapse.

3.3 Conclusive Remarks

The intrinsic complex nature of exercises and real events along with data collected from the observations supported the identification of emergency management procedures at the Emergency Operations Centre level. Such experiences were vital in collecting data and developing knowledge on organisational decision-making.

Although, the complex nature of emergency events was simulated by exercises, real events observations have indicated limitations in simulations. Hence, both approaches were synergic in helping to understand the environment and processes in which decisions take place.

Specific findings for each event/exercise were previously reported in the Case Study section. Those were achieved after compiling and analysing data under the flexible method proposed in sub-section 3.1.2. General findings are now reported according to considerations on the four decision-making domains (i.e. physical, information, cognitive and social).

- **Response operations**: interactions among individuals within an organisation occur under well defined structures such as the CIMS. However, inter-organisational activities seem to be performed without much standardisation;
- **Information loss:** the common process of logging received information on white boards has shown poor performances as reporting styles vary among people and events are highly dynamic. Additionally, the process cannot comprehensively take into account the numerous communication channels operating during an emergency (e.g. phone, fax, radio, cell phone, e-mail) therefore it is not able to accurately represent the event's unfold;
- **Lack of communication redundancy:** some observed organisations either did not have alternative communication channels in place or did not have staff capable to operate alternative technologies (e.g. satellite phones). Lack of communication redundancy often implied in information loss such as an observed organisation, which only became aware of a Civil Emergency situation after two hours it has been formally declared by the exercise controller. Many times such instances occurred as most of the communication and information sharing were performed using exclusively e-mails or phones;
- **Limited leadership:** although every team had a staff member assigned as a "leader", his/her influence was restricted to a team and it never crossed the "organisation's boundaries". Also at many observed exercises, the leadership role was limited and often underestimated;
- **Conflicting priorities and response goals:** limited communication implied in defining conflicting priorities as organisations defined individual objectives without considering the emergency situation in a holistic context (i.e. shared priorities, limited resource availability). It was also observed passive response behaviour at some organisations, which

can be possibly associated with poor communication as staff waited for priorities to be defined by external organisations;

- **Team work:** it is predominant in comparison to individual decision-making and management. All staff contributed by using the best of their knowledge and expertise in order to achieve efficient response. However, individual knowledge and expertise can still be better used when managing emergencies. For instance, it was observed wrong allocation of staff to particular roles, which consequently incurred in limited individual performances. In this sense, clear communication protocols, information systems, accountability/leadership skills, etc need to be developed, trained and implemented

Although observations added a considerable body of knowledge on extreme events decision-making at organisational contexts, they could not suffice all data and experiences needed to proposed the Dynamic Response Recovery Tool. In this respect, a complimentary research approach was developed. It is fully described in the next chapter along with its case studies, which finally supported the proposal of the DRRT.

4 UNDERSTANDING EXTREME EVENTS RESOURCE DEPLOYMENT

This chapter presents the development and application of a game based scenario simulation. This approach was envisaged as a way to overcome the limitations from the observation of emergency exercises in the context of physical resource deployment. The chapter begins with a brief review of the gaming techniques used for surveying purposes. The second section presents the development and design activities undertaken to create the game-based emergency scenario simulation. The third section describes the field tests and the final game package deployed for case studies. The reaming two sections are dedicated in explaining the proposed analysis method and reporting the series of case studies conducted in New Zealand.

4.1 Gaming for Surveying

The history of gaming can be tracked back to 1962, when a PDP-1 (Programmed Data Processor-1) was used to develop simulations at the Massachusetts Institute of Technology (McCarthy *et al.*, 2005). Despite its initial success, gaming simulations have not had a place within a formal branch in science until the eighties when Ellington *et al.* (1981) published a book entitled “Games and Simulations in Science Education”. The authors identified the lack of basic formal texts and source books on science-based gaming as a gap. This gap was seen to have impaired the technique’s development. This fact motivated Ellington and other authors to review early developments and to investigate a series of concepts and applications for gaming within research.

Against this backdrop, Ellington *et al.* (1981) reported the use of numerous simulations in the forms of cards and board games between 1970 and 1975. This was also when computer-based simulations became accessible to many universities and large organisations (e.g. IBM Research Centre – Peterson and Wahi, 1972). Over the next two decades (1980s and 1990s), gaming concepts were consistently developed and evolved for the purposes of both entertainment and surveying. For instance, the well known game SimCity 2000 (first released in 1993) originated from formal studies about urban dynamics (Peschon *et al.*, 1996) and resulted in a very popular entertainment and teaching tool (Adams, 1998).

Additional successful teaching and learning experiences (like those gained from SimCity) have encouraged researchers and practitioners to invest effort and resources into game simulation research and development. For instance, Fong (2006) reports numerous commercial games that have been adapted for military training. In such context, game simulations can focus on exercising the "use of information to alleviate the challenges in an urban warfare scenario" as well as understanding "issues surrounding information requirement and usage, sense making, and command and control" (Fong, 2006). Additionally, Belardo and Wallace (1989) report the evaluation of decision support tools through game simulation and Prohaska and Frank (1990) purely used simulations to investigate decision-making activities.

From the nineties to date, computer developments have created more sophisticated opportunities thanks to the greater flexibility and data handling capacity offered by the combination of hardware and software. Cognitive skills such as problem-solving and decision-making have been consistently practiced in game simulations. In recent years, Power (2003, 2005b) and Mendonça *et al.* (2006) have developed concepts and reported experiences using complex simulations that are used for the study of decision-making and decision-making support during stress laden situations.

No matter what field of expertise, game simulations have, over time, shown their fascinating capacity to emulate scenarios and practice real-life situations. Ellington *et al.* (1981) conclude that game simulations are useful for research as they can be highly versatile and flexible, unlike real situations observation. They can also achieve a positive transfer of learning (i.e. development of abilities and skills to be applied in real situations – Gagné, 1970).

Three formal concepts lay the foundations for game simulations: i) Game, ii) Simulation and iii) Case Study. In general terms, games are defined as contests between adversaries operating under constraints (rules) for an objective, while simulations are "operating representations of contextual features of realities" (Bloomer, 1973 *apud* Ellington *et al.* 1981). Finally, case studies are in-depth studies of a particular event, problem or situation (Walker, 1974). It ultimately targets knowledge development regardless specific circumstances defined by the case study (Van Wagner, 2009).

Although the abovementioned concepts are individually limited, a number of possibilities are created when they are combined. For instance, Bloomer (1973) describes the overlap between simulation and game as hybrid exercises or simulation games. Ellington *et al.* (1981) define the seven types of exercises as illustrated in Figure 4-1. We further explore "Simulation Games Used as Case Studies" because of its potential for this research.

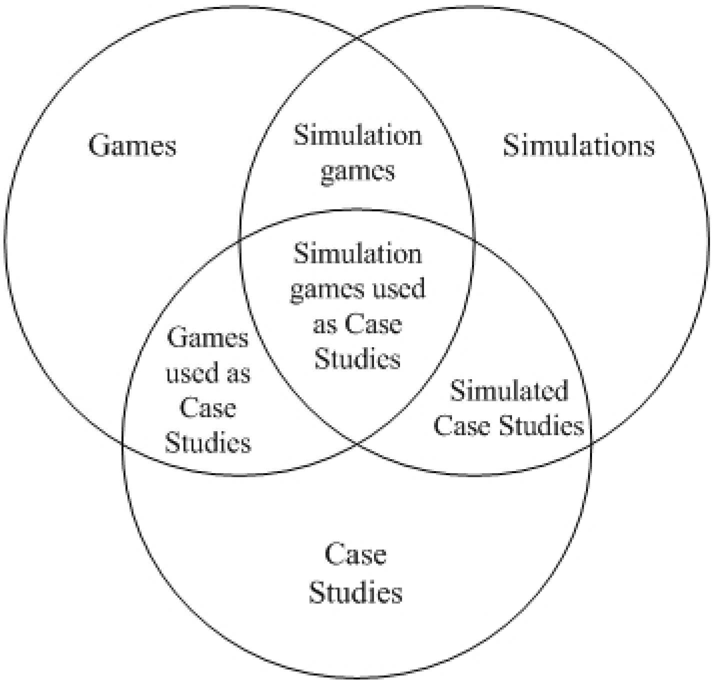


Figure 4-1: Relationships between Games, Simulations and Case Studies.
Source: Ellington *et al.* (1981).

The overlap of these three basic concepts (i.e. Simulation Games Used as Case Studies) is the most promising one for this particular research. This type of exercise can replicate a real ongoing situation (Simulation) under specific pre-defined rules (Game). Thus, particular events, problems or situations can be studied in-depth (Case Study) in order to answer research questions (which is meant to be the game's objective). Ellington *et al.* (1981) formally define Simulation Games Used as Case Studies as a class of exercises that has all the components from Games, Simulations and

Case Studies. This includes both small and large-scale simulations for teaching and interactive teaching, respectively. Some examples refer to “real” war games used for military training and computerised business management games.

In order to fully explore the approach described above, four development items should be properly considered (Peterson and Wahi, 1972). Initially, a scenario has to be created. This scenario defines the boundaries and set up limitations so that a controlled environment can be simulated. A scenario (also referred as an approximation model) emulates the reality surrounding the particular event, problem or situation under study. Scenario characteristics lead to two development needs, also regarded as game facets. One facet refers to the game’s interactiveness and the other to its instructions. The first one defines the dialog interface between player and game through the provision of multiple accesses and courses of events. The player only sees inputs and outputs in the forms of natural language (i.e. statements, pictures and etc), while the game platform runs the approximation model in a “black box” environment to ultimately perform all possible variations. The another facet provides teaching capabilities, as it helps the player to make inferences about the hidden model ruling the game simulation or the approximation model. Finally, game inconsistencies should be always expected no matter how well conceived and tested the game was. Thus, a game authoring tool should allow modifications to be quickly performed.

Along with having a straightforward development procedure, gaming techniques have shown potential for studying a number of subjects for almost five decades. Applications vary in complexity (e.g. board or computer based games) depending on the specific approaches, objectives and resources. Results reported by numerous authors have proven the applicability and success of gaming techniques, as well as suggesting promising opportunities for the future.

In this context, we aimed at developing a game simulation for the specific context of roading organisations. The main idea was to focus on a singular research subject (or individual) so that specific decision-making activities could be observed and recorded. By collecting specific data sets (further described in this chapter), we aimed at the identification of patterns of resource deployment, which can ultimately represent decision-making behaviour.

4.2 Game Based Scenario Design Protocols

The design task was initially tackled using a three step process comprised of Conceptualisation, Creation of a Prototype, and Testing (as illustrated in Figure 4-2).

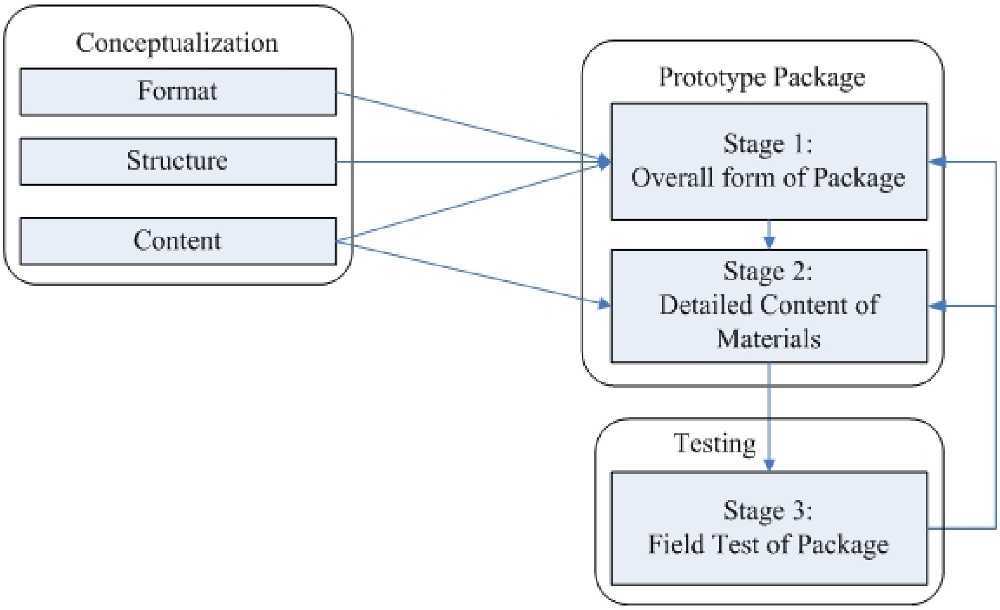


Figure 4-2: Converting a Basic Idea into a Viable Package.
Source: Ellington *et al.* (1981).

Aimed at designing a viable game package for the case of State Highway Organisations, the conceptualisation step defined the format, structure and content. A board game format was chosen based on simple graphical development needs in the context of the available information technologies. The structure accounted for the information dispersal during an emergency simulation, so that the scenario becomes clear to the player through a series of reports. This structure is very similar to the one used to run the exercises observed in chapter 3. A 7.2 earthquake on the Richter Scale, affecting a hypothetical city of 150,000 inhabitants featuring common urban systems (e.g. central business district, residential suburbia, commercial areas, industrial area, road network system, railway line), defined the game's content.

With the basic concept of the exercise set up, we drew up the initial prototype package descriptions. The general requirements to fulfil structure needs and content representation in accordance with the desired format were considered. The Prototype Package was created according to the following necessary components:

- Representation of transport networks such as roading and rail due to our intended focus on the transportation issues that arise during emergency events;
- Presentation of a common urban region, including a hospital, parks, an airport, commercial and administrational centres, a central business district, residential areas etc;
- Non-cluttered graphical board game;
- Injections of information in hardcopy formats;
- Physical resources numerically represented, i.e. number of available units of resources without distinction of type (e.g. diggers, trucks, temporary traffic management signage);
- Time limitations created for response in order to simulate the stress and pressures common to emergencies;
- Game to be played either by individuals or groups. Hence, no conflicts between parties are to be simulated;
- Exercise length limited to a range of 25 to 35 minutes to encourage participation.

At practical levels, the abovementioned design requirements have helped to shape final procedural ideas for the game simulation as well as to refine the content and define the list of materials needed (Stage 2). In general terms, the game intends to present the user with a board representation of an urban area, a specific number of physical resources to be managed and a time limitation device such as chronometer or the exercise controller himself/herself. The simulation shall be operational through a series of injects in hard copy formats given to the participant at the beginning of each response day. Finally, the simulation's rules allow the participant to ask the exercise controller about possible additional information not presented in the injects. However, additional information will only be provided on the basis of the scenario development and the specific query of the participant.

Finally, the prototype package (Stages 1 and 2) can be summarily described as been an emergency scenario simulation containing a board game, resource limitation techniques and injects. The board game, resources and hardcopy injects include within them the materials needed to run the simulation. The following section describes how the field test package was developed during pilot testing, and finally the Game-Based Scenario Simulation.

4.3 Pilot Test and Game Based Scenario Simulation Package

The first version of the game (i.e. board, scenario's injects, simulation procedures) was implemented and tested in order to finalise the process described in Figure 4-2. Alongside developing the game we have set up testing routines based on simple procedures and volunteer participation (e.g. fellow research colleagues). A number of participants (initially unaware of the research objectives) were asked to "play" the game and report their impressions, feelings and suggestions for improvement. The testing was performed in two rounds with five different people. Thanks to this process, great improvements were made to both the graphical design and the scenario specification. For the sake of simplicity, we present here only the final version of the game simulation.

The simulation was graphically designed using simple tools to create the board game (Figure 4-3) and the emergency scenario. The board game is associated with a set of events referred to as injects, which ultimately define the emergency scenario. Injects are designed to dynamically present data and information about the extreme event under simulation. Both the board and the injects were developed simultaneously and checked against each other in order to avoid inconsistencies.

Operationally, a few rules were created to keep the experiment uncomplicated and interesting for the participant. Thus, the participant could not make use of any external resources (e.g. computer, response manual, maps) or ask for support from work colleagues during the simulation due to the individual style of the game. Information is only given in the form of hardcopy injects presented to the participant at the beginning of each simulated response day or sometimes as the result of further enquiries made of the exercise controller. In this case, a proper query should be directed to the person in charge with a clear message about the information desired, e.g. "What is the level of damage at the bridge over the river (link 14)?" Additional information could then be provided to the participant according to the exercise flow, i.e. none, incomplete or complete additional information.

Following the design descriptions defined at Stage 1, the experiment was to be limited to a 25 – 35 minute period accordingly to the participant's ability to make the decisions. This was assumed to be a good length of time in terms of encouraging participation, based on impressions gained during the pilot simulations and suggestions made by the volunteers involved in the trials. Within this time frame and the specifics of the scenario, we limited the number of resource deployments to five. Each deployment represents a response day and should take approximately six to seven minutes. If resources were not deployed after this deadline time, this would be considered a *status quo* resource deployment decision and the simulation would continue the following response day.

Experiences acquired during the observation and analyses of simulated exercises and real events were used to develop a data collection method to capture response planning. The Analytical Hierarchy Process – AHP (Saaty, 1996) was chosen as it is a structured and extensively applied technique in the engineering decision-making science, which helps to deal with complex decisions and judgments (Saaty, 2008; Zahedi, 1986).

The AHP is a pragmatic process in which various elements from a basic structure are pairwise compared until all combinations are exhausted (Virginia Tech, 2010). Comparisons can be performed either by using concrete data about the elements or personal judgments on elements' meaning and importance. The process ultimately allows the conversion of cognitive judgment into numerical values. The final outcome of the AHP methodology is the estimation of weights or priorities for each element under consideration in a rational and consistent manner.

The AHP method was vital in this research stage as the literature review (chapter 2) indicated that extreme events decision-making is a complex and interdependent process. The observation of emergency exercises and real events (chapter 3) confirmed that previous knowledge, personal experiences, organisation procedures, response plans, resource availability and so on need to be considered when managing extreme events.

Hence, a powerful approach such as AHP could capture the existing complexity in prioritising objectives during an emergency as well as ensure that data collected (i.e. weights assigned by participants) is consistent. In this context, the AHP method was used to certify that the game based scenario simulation and collected data would indeed represent common challenges and decision-making actions performed during emergency situations.

The AHP was applied in this research by requiring game participants to fill a so called Importance Matrix (

Table **4-1**). This matrix was designed to acquire data about how participants strategise their response (also referred in this study as priorities) and assess the consistency of the weights assigned to each pair of objectives (blank cells in

Table **4-1**). By using Saaty's Consistency Ratio (*CR*) (Saaty, 1994) and estimating eigen values for all elements in the matrix according to the AHP method, we could ensure data consistency as well as a scientifically sound process to determine response priorities. In summary, the AHP method offered a complete suite of tools allowing the analysis of the complex prioritisation process performed by participants in the light of multi-criteria weight assignment.

In the context of emergency management and game simulations, the Importance Matrix was vital in validating the research approach taken in this thesis. Initially, the game is considered to be an independent experiment aiming at understanding extreme events decision-making processes applied by distinct organisations and staff. Thus, the matrix should supports a data collection conferring the flexibly needed to analyse the simulations according to individual participants' decision processes, prioritisation schemes, resource allocation routines and so on.

The development of the Importance Matrix was necessary as case study participants were selected from a range of organisations involved with emergency management and not only roading organisations. Hence, decision processes and priorities were expected to considerably vary amongst groups under study. Finally, response plans and priorities are commonly qualitatively described in emergency manuals. Therefore, it was required to propose a method, which would convert a qualitative scheme in numerical values for further analyses.

In essence, the Importance Matrix operates as a benchmarking tool. Its data collection procedure as well as weight assignment consistency check and priorities estimation allow us to study decision-making processes applied by different case study participants in a common ground. It is therefore possible to compare performances without biasing results or compromising the realism of the analyses. An illustration for such a scenario would be the assessment of decisions made by two distinct groups of participants. Consider one group with strong priority towards road accessibility (i.e. accessibility between communities and external support) and another with focus on immediate rescue and lifeline support. The numerical estimation of priorities makes possible to correctly assess and understand the decision-making process adopted by each group in terms of resource allocation. Thus, the analysis is substantiated by comprehensive data for both response planning and decision-making (resource deployment), which ultimately confers real value and accuracy to the process.

The matrix is to be filled in before the formal beginning of the simulation so that the data collection is not biased with experiences gathered during the scenario simulation (e.g. lessons, criticisms, limitations). On a practical level, the participant had to fill in the blank cells in

Table **4-1** using the relative scale given; in this way their priorities for each objective could be estimated. Although assigning pairwise comparison weights for eight items is a complex and demanding process, it provides the researcher with comprehensive information regarding priority consistency ratios, conflicting priorities management routines, relative priorities etc.

Table 4-1: Importance Matrix.

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							
Protect Private Property		1						
Support Lifelines			1					
Protect Economy			1/7					
Protect Environment					1			
Enable Support from other Areas						1		
Repair Key Infrastructure		5					1	
Facilitate Accessibility Between Communities								1

Support Lifelines is much more important than **Protect Economy**

Repair Key Infrastructure is strongly more important than **Protect Private Property**

Scale to be used

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

During the simulation, data is collected by observing/recording the number of resources deployed to each road link and directly enquiring as to the motivation behind particular deployments. After the given time (of approximately six minutes), the number of resources deployed to each road asset and the participant's statements regarding his/her decisions were recorded. Data was collected in such way so both quantitative and qualitative data were made available for subsequent analyses. Finally, upon the completion of the simulation, a semi-structured interview was conducted, aimed at gathering information on a participant's general decision planning and decision-making (i.e. resources deployment).

All data is to be analysed under the specifically designed method presented in the next sub-section. The remainder of this sub-section briefly describes the specific scenario that accompanies this board game (Figure 4-3).

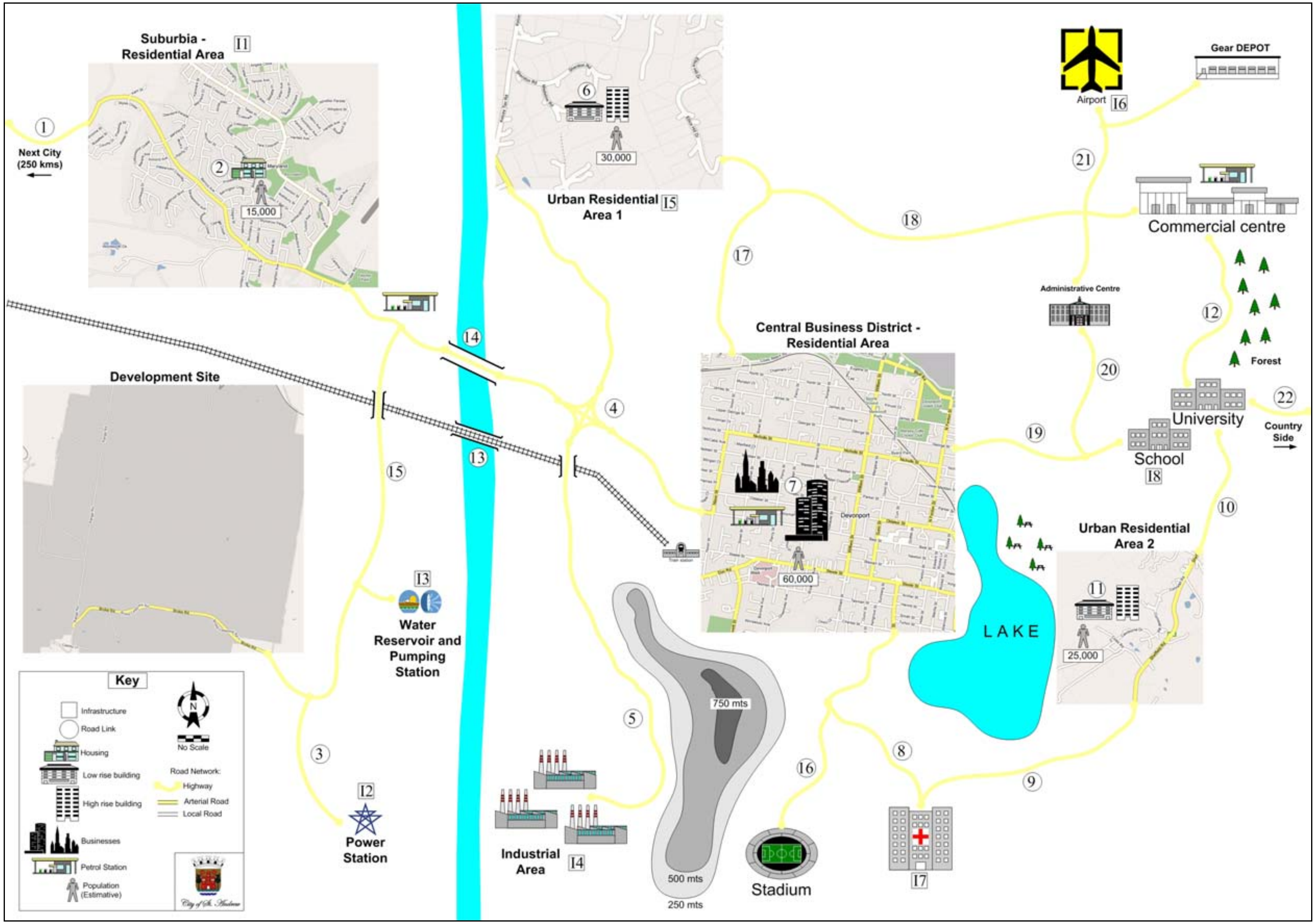


Figure 4-3: Board Game.

The proposed earthquake scenario evolves similarly to a real event. Only general situations and superficial information are initially provided to participants on the first day, while specific data (e.g. damage, affected people, resource needs) are progressively made available on subsequent days. This simulates an evolving event, in which infrastructure assessments, lifeline situation reports, Civil Defence response operations, etc are provided as time elapses so response actions can be decided on.

The scenario develops over a five-day period after a major shock in a hypothetical urban region. The event affects a city of around 150,000 people and damages roading systems, buildings/houses, businesses etc. As previously mentioned in the game rules, additional information can be acquired from the exercise controller, depending on the participant's queries. That being said, all the information needed to proceed with a response is made available through injects given to participants during the simulation.

Table 4-2 presents the detailed scenario injects (or game content) to be made available to participants on a "daily basis". Observe that the emergency situation develops over time with a series of events as well as how the information accuracy increases over the response process. In this context, the five day event is described as follows:

- Day One – superficial damage information about major transportation infrastructures is obtained from various sources. For instance, the road bridge over the river (road link 14) and the interchange (road link 4) are only reported as being damaged, without any additional information. Response priorities are also established and circulated among response organisations by the Ministry of Civil Defence and Emergency Management. The main challenges during the initial response day are balancing priorities in terms of the key road links (e.g. external access and main bridge over the river) and the central business district roads, and strategising a response plan without much information about damage in many affected areas;

- Day Two – building upon the events from the first day, information about previous damage is updated. The information provided is the result of formal assessments conducted during the first day, as well as public information collected and confirmed by the Civil Defence. At this stage, with an increased volume of damage information, the challenge lies in comprehending the most immediate needs according to the available resources, so that response plans can be quickly and effectively re-structured if needed. Finally, two injects (the immediate needs to have access to the power station and to increase traffic flow at the damaged bridge over the river) are provided in order to overwhelm the decision maker so the simulation can reach real life complexity levels;

- Day Three – specific damage information is given regarding numerous components of transportation infrastructure. This ultimately creates a very complex decision environment with many conflicting priorities (the needs of the hospital, airport etc., issues such as river contamination) and limited resource availability. The imminent collapse of the main bridge (link 14) creates an urgent issue to be managed in order to keep the network connected. The main bridge allows for a more immediate response in the face of so much damage. Problems with water contamination and the need to arrange an alternative supply increases the complexity of the scenario in comparison with the previous day;

- Day Four – the scenario situation does not change much during the fourth day and the only new piece of information comes via a phone call from field personnel reporting chaos and traffic problems in the Residential Area 1. A TV media update to report current response efforts and future plans needs to be given at the end of the day. Although little new information is given, the participant is still challenged to manage the very complex situation from day three as well as to keep the situation progressing. The participant needs to keep tracking the number of resources deployed and needed according to a number of different priorities – this can easily overwhelm the decision maker; and

- Day Five – similarly to day four, little information is added in terms of damage assessments and network operations. A series of faxes from numerous organisations (e.g. rail companies, contractors and consultancies) are given to the participant in order to represent the common process of information overload during emergency events. Thus, the intention is to simulate the latter stages of response when most information has already been collected and information overload is experienced due to lack of organisational information sharing.

Table 4-2: Game Scenario Development.

Location / Inject	Injects				
	1st Day	**2nd Day**	**3rd Day**	**4th Day**	**5th Day**
Link 14: Road bridge	- 1 lane operational - Resource need: 15 units	- Traffic overload - Assessment update due to next day	- Assessment: imminent collapse if the immediate deployment of 7 units of resources is not done	Nil	Nil
Link 1: Access to neighbour city	- Additional resources from CD - Resource need: 10 units	Nil	Nil	Nil	Nil
Link 2: local suburbia roads	- Housing debris - Unknown resource needs	Nil	Nil	Nil	Nil
Fire at industrial area	- Unknown details of cause if fires - Limited access to site by Link 5	- Link 5 restricted to small vehicles - Unknown resource needs	- Resource need: 6 units	Nil	Nil
Link 7: local CBD roads	- Building debris - Petrol stations non accessible - Difficulties to commute - Resource need: 6 units	Nil	Nil	Nil	Nil
Link 4: road interchange	- Unknown damage	- North access to Residential Area 1 blocked - Resource need: 15 units	Nil	Nil	Nil

Table 4-2: Game Scenario Development (cont.)

Location / Inject	Injects				
	1st Day	**2nd Day**	**3rd Day**	**4th Day**	**5th Day**
Link 13: rail bridge	- Collapsed - Resource need: 20 units	Nil	Nil	Nil	Nil
Link 3: access to power station	Nil	- Restricted to small machinery - Power station partially operational - Resource need: 7 units	Nil	Nil	Nil
Link 12: link between commercial and educational centre	Nil	- Road closed due to fallen trees - Resource need: 6 units	Nil	Nil	Nil
Link 8: access to hospital	Nil	Nil	- Partially closed - Resource need: 4 units	Nil	Nil
Hospital needs	Nil	Nil	Water Power Medial supplies	Nil	Nil
River contamination	Nil	Nil	Water contaminated due to chemical spilling from industrial area	Nil	Nil

Table 4-2: Game Scenario Development (cont.)

Location / Inject	Injects				
	1st Day	**2nd Day**	**3rd Day**	**4th Day**	**5th Day**
Residential Area 1	Nil	Nil	- 1 building collapsed - 300 people missing, 50 dead, 200 in need of hospital treatment - Local roads need cleaning to facilitate search and rescue	- Resource need: 5 units	Nil
Link 2: local roads at Suburbia	Nil	Nil	- Housing debris - Resource need: 4 units	Nil	Nil
Link 11: Local road at Residential Area 2	Nil	Nil	- Building debris - Resource need: 3 units	Nil	Nil
Link 10: access to Residential Area 2 (by Educational centre)	Nil	Nil	- Closed - Resource need: 15 units	Nil	Nil
Link 9: access to Residential Area 2 (by hospital)	Nil	Nil	- Partially closed - Resource need: 6 units	Nil	Nil
Report / Communication	Nil	Nil	Nil	Nil	- Geological Services - Railway company - CR Engineering: development site availability

4.4 Analysis method

The proposed Game-based Scenario Simulation Analysis Method aims at processing both the quantitative and qualitative data collected during game simulations in order to identify decision-making processes and patterns. Information generated from these data helped us to understand influencing factors, key information, prioritisation schemes, and, ultimately, decision-making variables in the context of emergency management (within roading organisations). Although the game was carefully designed and a specific case study was defined (i.e. roading organisations), we could not pragmatically envisage a rigid analysis process due to the complex nature of emergency management and high cognitive levels of extreme events decision-making.

The method has three phases, as illustrated in Figure 4-4. Each phase targets the accomplishment of a specific goal in order to progressively analyse decision-making during extreme events. As shown in Figure 4-4, data is initially filtered into two classes: qualitative and quantitative. Quantitative data is processed first, due to these data being more suited to numerical analyses and more widely represented in engineering contexts. Nonetheless, qualitative data is used to complement those analyses where quantitative sets did not sufficiently meet data needs. The analysis is concluded either by extracting general knowledge or specifying an extreme event decision-making model based upon results achieved for both response planning (Importance Matrices) and decision-making response (resources deployment).

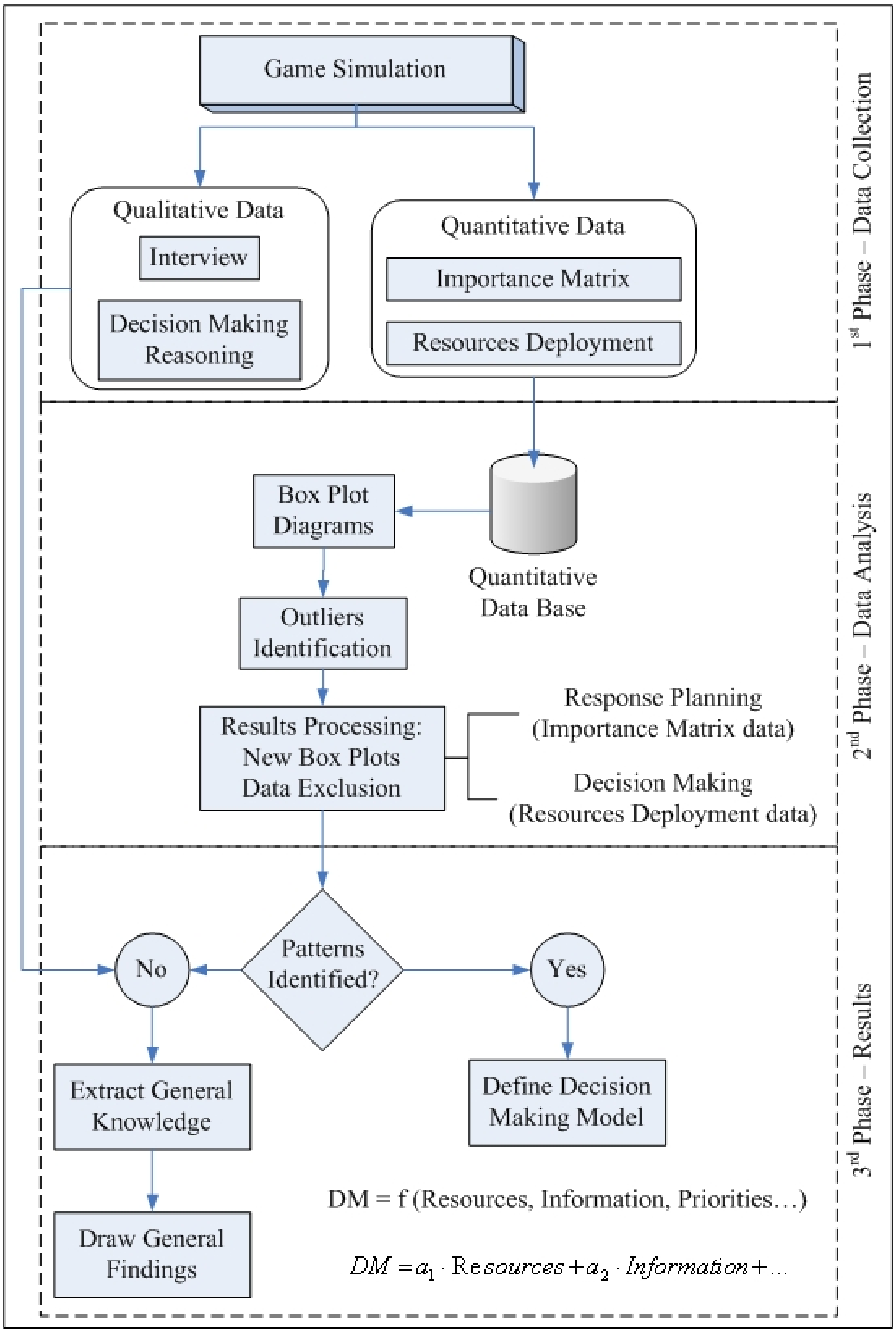


Figure 4-4: Proposed Game Analysis Method.

The first phase involves collecting and organising data from different simulations into two data sets. These two sets will contain both qualitative data (audio records/transcripts of interviews and the reasoning stated for each decision made) and quantitative data (number of resources deployed to each road link per day and Importance Matrix's weights). The aim is to facilitate further analyses by using only two sets without compromising individual analyses.

The second phase targets the identification of commonalities or patterns among participants. This is achieved by generating box-plot diagrams for the intended classes of data and identifying outliers and excluding them from the data set. Updated box-plot diagrams should be then generated in order to identify decision-making patterns. It is important to consider the number of outliers in terms of the total population, as large numbers do not indicate patterns by themselves. This proposed data analysis method is made extremely simple to facilitate the analyses of both response planning and decision-making responses, as described below.

Data from the importance matrices (

Table **4-1**) is used for the analysis of response planning. A Consistency Ratio (Equation 4-1) is proposed according to Saaty (1994) for a quick assessment of the weights assigned by the participant. Saaty's original concept of *CR* aims at verifying if the decision maker is being random and/or illogical in the pairwise comparisons (Xu *et al.*, 2008).

$$CR = \left(\frac{1}{RI}\right) \cdot \left(\frac{L_{\max} - n}{n-1}\right) \quad \textbf{(4-1)}$$

Where: n – number of items considered in the Importance Matrix;
RI – Random Index;
L_{max} – Largest eigen value of the Importance Matrix;
$CR \leq 0.10$ for n greater than 4 (Saaty, 1994).

At the end, we estimate priorities for each response objective using Equation 4-2 as follows.

$$P(RO_i) = \frac{\sum_{j=1}^{n} \left(w_{ij} \Big/ \sum_{i=1}^{n} w_{ij} \right)}{n} \text{ ; given } 1 \leq i \leq n \quad \textbf{(4-2)}$$

Where: $P(RO_i)$ – i^{th} Response Priorities;
i – row items;
j – column items;
n – number of row items or column items;

w_{ij} – importance or weights assigned by participant;

$1 \leq i \leq n$;

$1 \leq j \leq n$.

The analysis of response planning is concluded by plotting box plot diagrams and identifying outliers in order to find commonalities and prioritisation patterns among participants.

The Decision-making Response is similarly analysed (i.e. by plotting Box Plot Diagrams and identifying outliers). However, data from the resources deployed to each road link shall now be used. It is strongly recommended that data be used in a temporal fashion (i.e. resources deployed per response day) to assess how situation awareness develops and response processes change throughout the scenario.

Finally, if the results obtained indicate patterns then a mathematical modelling development of extreme events decision-making shall take place in the third phase. This process will define variables, parameters, and ultimately equations, so as to describe the decision processes. Specific techniques for numerical modelling are not proposed yet as they may vary considerably (as a result of data availability, findings and local culture/environment). On the other hand, if patterns are not clearly identified then the analyst should extract general knowledge from the experiences acquired. Thus, further findings regarding the decision-making processes applied by participants can be drawn in future studies. In this particular case, it is envisaged that there are potential additional contributions from the qualitative data collected in the first phase.

4.5 Game Simulation Case Studies

Twelve case studies were conducted over a 3-month period. They included local and national roading authorities, consultants, and contractors with nation-wide operations. Organisations' and participants' names were suppressed due to privacy requirements and Human Ethics regulations (refer to Appendix A for University of Canterbury's Human Ethics Committee Approval). The results achieved are reported in terms of their phase below.

- 1st Phase – Data Collection:

The twelve case studies were initially considered suitable for analysis based on participants' conduct and general decision-making and management performances during the simulations. All data collected were organised according to Phase 1 requirements and qualitative and quantitative data sets were organised. Appendix B presents the quantitative data collected from Importance Matrices and Resource Deployments. Qualitative data (e.g. interview records, comments, suggestions) remain in digital audio format, as it would demand too many human resources (and funding) to be transcribed.

- 2nd Phase – Data Analysis:

Phase 2 incorporates the analysis of quantitative data for both the Response Planning and the Decision-making Response. Planning accounts for the structured response strategy defined by the participant previously the simulation. This data was recorded by asking the participants to fill in the given Importance Matrix. The Decision-making Response is the actual response process, limited in the proposed game-based simulation to the number of resources deployed to each link on the road network during the five simulated response days. Both planning and response stages are individually analysed as follows.

- Response Planning:

Data from Importance Matrices were initially assessed in order to identify random or illogical pairwise comparisons (Saaty, 1994). Consistency Ratios (Equation 4-1) were estimated for each of the twelve participants. The results shown in Table 4-3 indicated the need to withdraw participants B, D, E, J, K and L from the study due to a lack of consistency (according to Saaty's recommendation, i.e. CR equal or smaller to 0.10). However, a secondary analyses indicate that participants' behaviours were appropriate during all simulations conducted so none participant was excluded from the data set. Inconsistent CRs presented in Table 4-3 can be associated with difficulties to fill the proposed Importance Matrices as assigning exact pairwise comparison weights to emergency response objectives can be a complex and demanding task. Some participants highlighted that prioritizing objectives using the proposed multicriteria approach was too difficult in face of many complexities to be considered when dealing with emergency events. This fact aligns with findings from the study conducted by Buckley and Uppuluri (1984), which discusses the advantages and disadvantages to use exact pairwise comparison ratios, flexible weighting criteria (such as fuzzy weights) and other alternative approaches to reduce bias and imprecision in multicriteria data collection.

Table 4-3: Consistency Ratio.

	Consistency Ratio
Participant A	0.053
Participant B	0.165
Participant C	-0.038
Participant D	0.684
Participant E	0.252
Participant F	0.009
Participant G	0.015
Participant H	0.048
Participant I	0.030
Participant J	0.111
Participant K	0.384
Participant L	0.207

Hence, exclusively using Saaty's Consistency Ratio appears inappropriate when deciding who will be excluded. The exact pairwise weights could not incorporate all the complexities that exist in emergency management. Saaty's Consistency Ratio was judged limited in the context of this research as it only considered data from the Importance Matrices and not from the remaining parts of the simulation (e.g. resources deployment, reasoning statements, participant's behaviour, individual experiences and skills). Hence, Saaty's CR was not used as the unique parameter to disqualify participants.

Data consistency analyses were performed along with pattern identification as the analysis framework (Figure 4-4) was designed to incorporate unforeseen data and/or processes limitations. Priorities were initially calculated for each response objective and associated participant using Equation 4-2. The results shown in Table 4-4, which represent the importance of each response priority in a percentage value, were used to plot a Box Plot Diagram and individual priorities for all twelve participants (Figure 4-5). Visual analysis of the Box Plot Diagram indicated a series of potential outliers (observations numerically distant from a pattern or cluster of data), which were highlighted in red in Table 4-4. Those values represent differences among individual prioritisation schemes applied by participants. Additionally, extreme values are possibly associated with misjudgements or misinterpretation of the multicriteria method required to fill the Importance Matrix. Ultimately, such results validate the intended research approach posed by Importance Matrix as it reflects the complex and overwhelming reality dealt when managing emergencies.

Median priorities values for all participants are plotted in Figure 4-6. It indicates that decision makers have the tendency to prioritise "Support Immediate Rescue" during response activities (i.e. immediate aftermath of the event). Been the highest priority objective also incurs in randomness due to different possible approaches to be taken. Common values were set at the 0.30 mark although some participants have assigned very low or very high priorities for this specific objective. In the specific New Zealand context, it can be argued that underestimation rises from the assumption that Civil Defence's recommendations (e.g. maintain provisional supplies for three days, community engagement) would be strictly obeyed by general public. On the other hand, overestimation can be associated with misconception of response planning by not taking into consideration conflicting priorities and the common multi-task nature of emergency management needed to be taken into consideration.

Interestingly, the results have shown the commonalities tend to a particular study conducted by the Canterbury Engineering Lifelines Group (CELG, 2007). In the context of route prioritisation, community priorities were ranked as follows:

- Restoration of services providing an immediate threat to public health and safety (e.g. hospitals, ambulances, fire fighting services);
- Restoration of supply to emergency services sites (police, fire service, Emergency Operations Centres);
- Restoration of supply to key infrastructure sites requiring service for their own recovery such as Lifeline Utilities (including energy, telecommunications, water, wastewater, transport);
- Restoration of services to key organisations that have been identified members of a welfare advisory group or similar;
- Restoration of supply to major construction resources, to which access would be needed in the response and recovery phase (including contractors, materials, plants); and
- Restoration of services to schools.

An interesting phenomenon has been identified at medium priority levels (i.e. support lifelines, enabling support from other areas and repairing key infrastructure). The issue relates to the cognitive process used to balance conflicting and interdependent resource needs and availability. Medium priority objectives are flexibly incorporated into the emergency management and response planning. This happens due to the need to cope with the escalating nature of disasters, which can impose sudden challenges in response to unexpected events. Using this approach, medium priority objectives can be adapted according to real time needs; in this way the core response objectives can be maintained.

In spite of the many differences between high, medium and low priority classifications, there is a general trend in the way that responses were planned by the participants before the simulations. Initially, their response is focused on attending affected people in order to save lives (usually the greatest priority during the immediate aftermath of disasters). Search and Rescue is a time dependent objective, as affected people have a limited time span to receive support before they eventually perish (e.g. the 72 Hour Rule for earthquake events). Nevertheless, immediate rescue is not the only thing considered, as it only accounts for 33% of priorities. There is still a large margin for alternative objectives. In the specific simulations conducted in this research, 47% of priorities correspond to three objectives rated as medium priority (support lifelines, enable support from other areas and repair key infrastructure) and 20% for the remaining objectives or low priority responses. These facts show a response pattern among participants in which flexibility allows improvisation when unforeseen events occur. Response planning also considers a multi-objective approach as human life depends on resources (e.g. medical infrastructure, medicine, potable water, power) and critical systems are commonly interdependent. Ultimately, the response planning stage indicates decision processes aligned with the conceptual background of Naturalistic Decision Models (use of comparisons, reasoning, assumptions, facts/data, etc.) as incomplete, complex information needs to be considered and understood before strategies can be agreed upon.

Table 4-4: Response Priorities.

		Support Immediate Rescue (%)	Protect Private Property (%)	Support Lifelines (%)	Protect Economy (%)	Protect Environment (%)	Enable Support from other Areas (%)	Repair Key Infrastructure (%)	Accessibility Between Communities (%)
Participant	**A**	44.46	3.05	10.68	5.34	2.37	15.41	12.46	6.23
	B	33.86	11.59	15.35	5.11	5.53	8.96	11.74	7.86
	C	18.47	3.64	20.82	5.98	6.76	18.30	15.56	10.46
	D	11.65	10.80	18.14	3.08	3.45	20.23	9.68	22.98
	E	34.21	1.80	03.23	6.13	6.73	13.86	14.22	19.82
	F	31.82	21.10	12.21	4.56	4.50	8.11	11.60	6.11
	G	32.94	8.73	18.87	3.33	3.14	9.56	16.76	6.67
	H	21.24	8.13	14.56	4.41	5.73	26.56	9.66	9.70
	I	31.62	2.07	29.22	1.94	4.55	16.40	9.17	5.02
	J	16.02	2.50	11.89	8.97	8.12	17.96	17.27	17.27
	K	35.21	1.64	19.77	3.27	11.96	8.01	13.92	6.22
	L	30.21	1.56	26.58	2.25	7.58	8.39	14.47	8.95

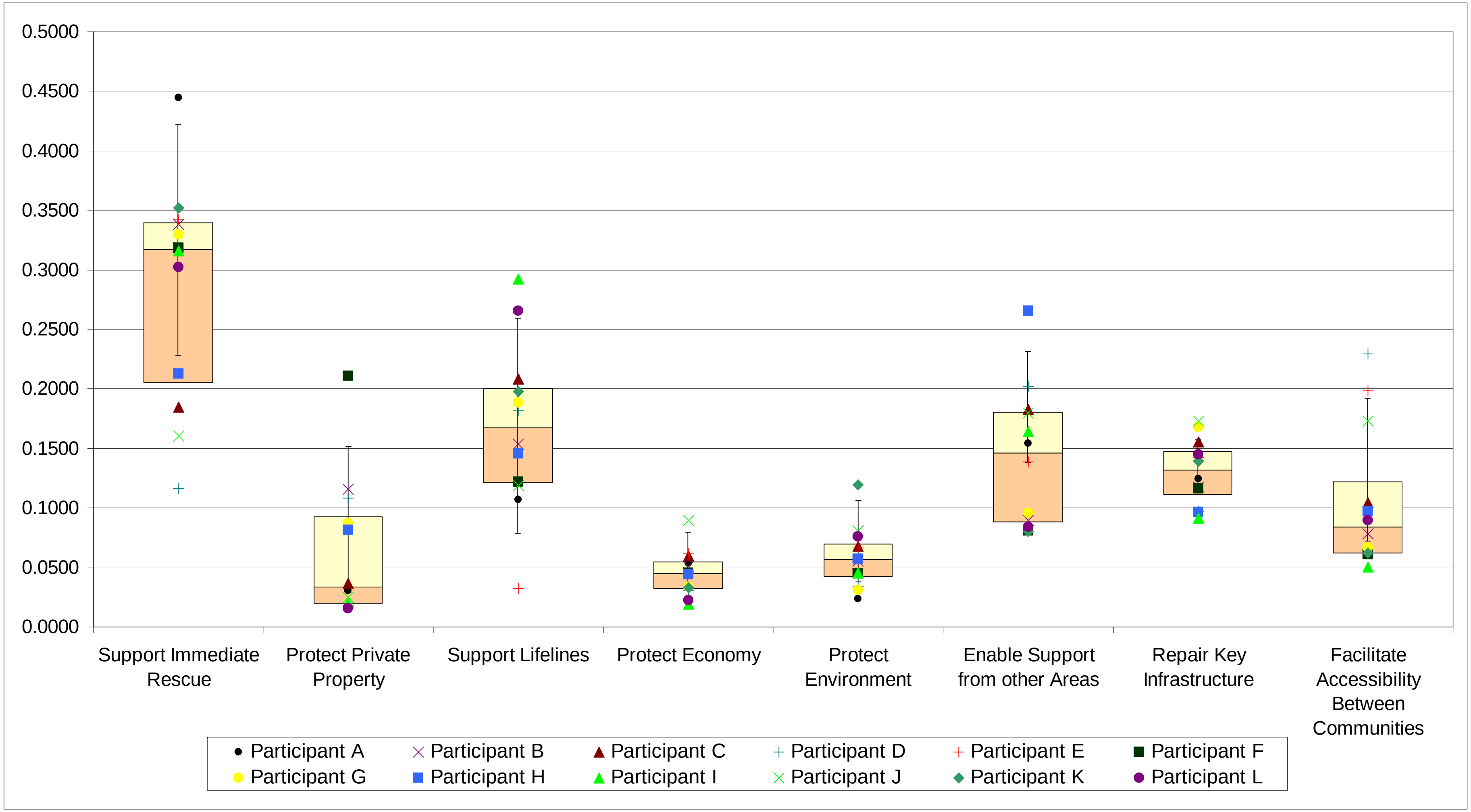


Figure 4-5: Box Plot Diagram and Outliers.

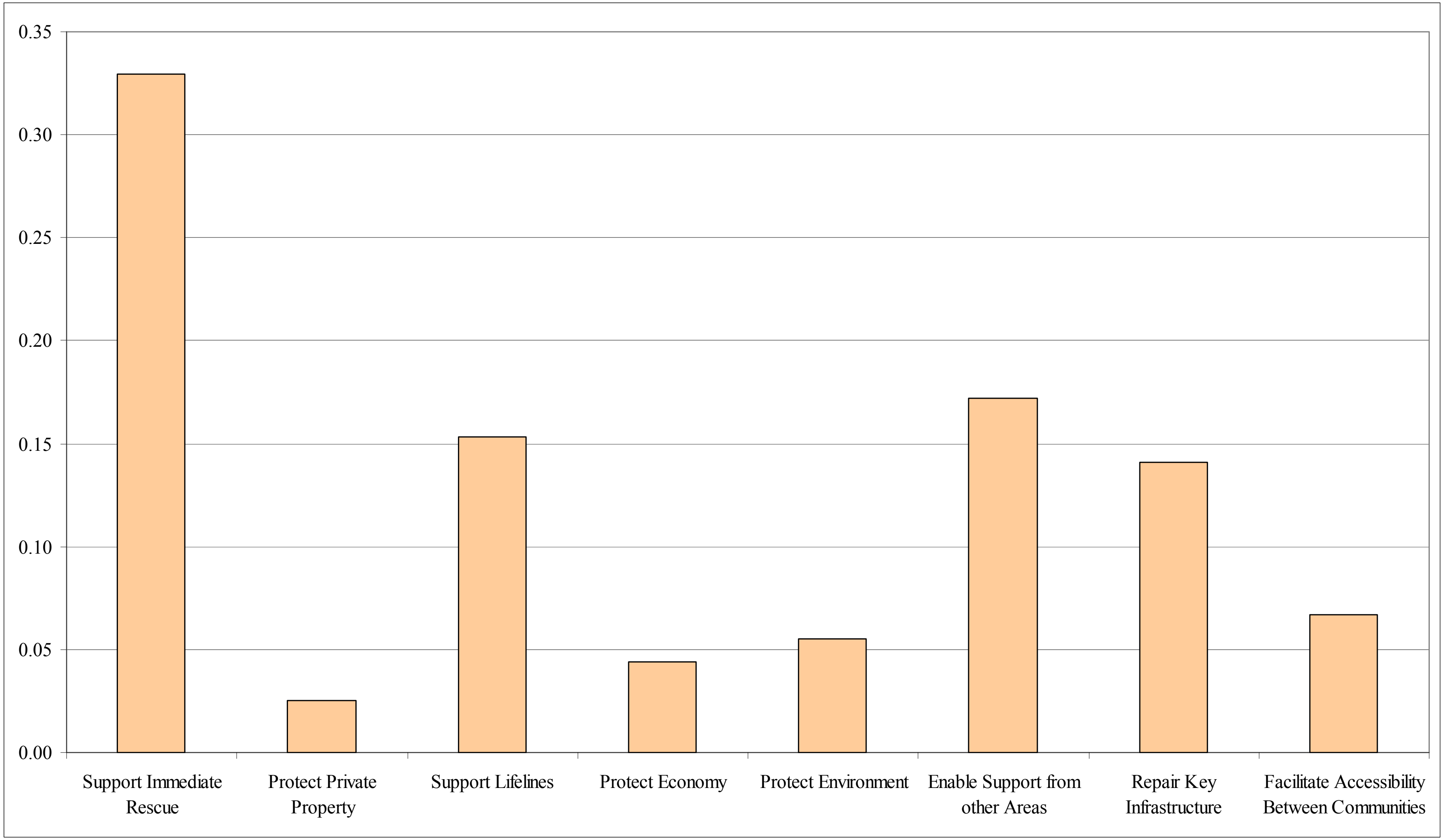


Figure 4-6: Final Median Values for Response Priorities.

- Decision-making Response:

Similarly to Decision Planning, we initially plotted a number of Box Plot Diagrams to support the identification of patterns. To do so we have used the data regarding the number of resources deployed daily to each road link. Figure 4-7 illustrates these data, which is presented in its raw format in Appendix B.

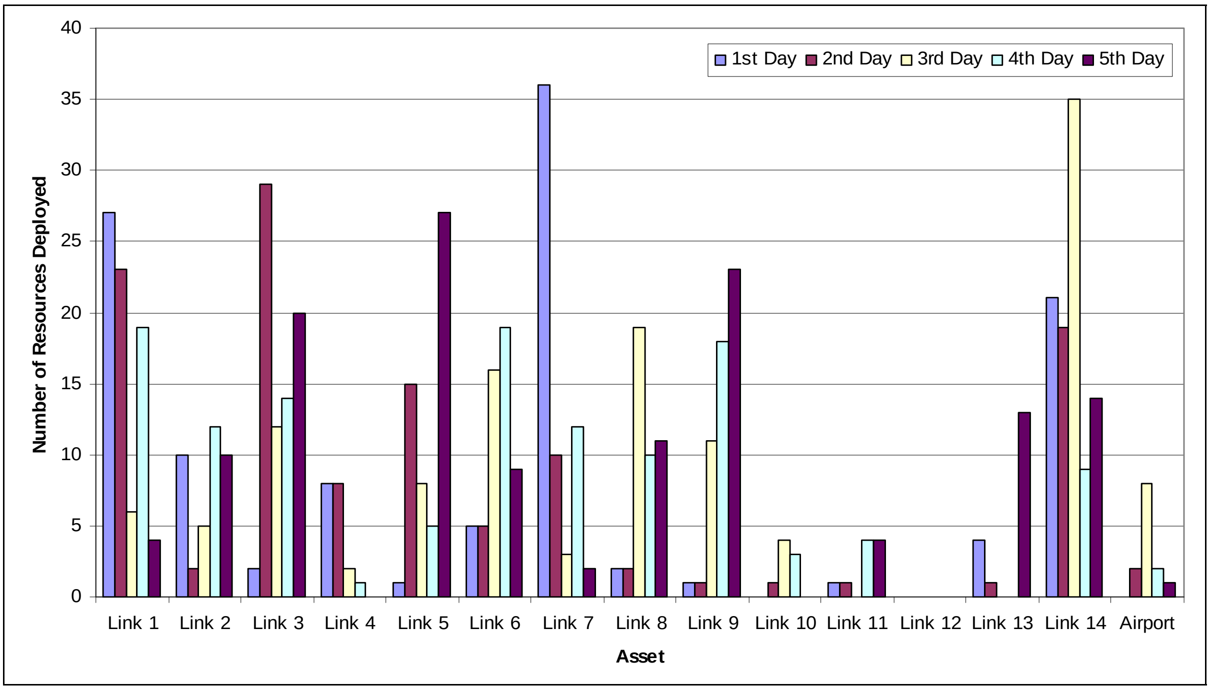


Figure 4-7: Daily Resource Deployment.

Unlike the previous analysis conducted for response planning, Box Plot diagrams did not indicate any patterns. The variations were far too great to argue for the existence of commonalities in the way that physical resources were deployed to specific links of the network during the simulation.

Against this backdrop, a complete review of both the scientific literature and practical experiences used to inform this research (i.e. observation of exercises and game simulations) was needed to support an alternative approach to decision-making response analysis. AELG (2005) reports that numerous organisations depend on road networks to conduct their own response. Observations of emergency exercises have demonstrated that roading authorities set priorities and make decisions according to external organisations' needs as events unfold. Many of the participants interviewed at the end of each game simulation stated that resource deployment depends on the potential benefits predicted according to existing needs. For instance, the deployment of resources to a specific link might be decided upon because it would potentially increase the road service access to a power plant while also supporting relief operations and evacuation.

Deployment strategies were mostly focused on spreading resources throughout the affected region in order to attend multiple priorities simultaneously. Response from participants (who were required to play the role of transport managers) has shown to target external priorities and not internal ones. It means that response was conducted aiming at providing organisations involved with the emergency with the best possible road network.

Following such principle, we estimated (according to the game's design) how each road link could contribute to the eight response objectives presented in the Importance Matrix. Table 4-5 illustrates the weighting system used to estimate how response objectives were fulfilled by the deployment of resources to individual links.

For instance, participant A adopted a strategic response during the simulation. His initial decisions were focused on re-establishing the link with the neighbour city to have an external link as well as to collect additional resources. Nonetheless, CBD local roads and the major bridge were also prioritised. Shortly after that, resources were relocated into the suburbia's local roads and to the access to the industrial area due to potential hazards to the river. With the re-opening of the major external link and additional resources from the neighbour city, his priorities were once again re-assessed and resources re-directed to support lifelines (e.g. hospital and power station) and to maintain the critical road bridge link operational. In the second half of the simulation, decisions continued to be strategically made, which finally culminated with ten out of fifteen damaged road links re-opened.

Another interesting example of response was observed with participant E. This particular individual presented a long term strategic response. Resources were very much scattered throughout the affected area so a number of communities could be attended. In spite to the CBD, all badly affected areas had at least one resource working on site. Priorities were also changed in face of potential catastrophic events and most of objectives were to be accomplished at similar times. As a consequence, not many road assets were operational (four out of fifteen) at the end of the simulation. Nevertheless, three assets (local roads at both the Residential Area 1 and CBD and access to the Hospital via the CBD) had very limited levels of damage at the end of the fifth day, meaning they could be shortly re-opened at full capacity.

Table 4-5: Response Objectives and Road Network Weighting System.

	Support Immediate Rescue	Protect Private Property	Support Lifelines	Protect Economy	Protect Environment	Enable Support from other Areas	Repair Key Infrastructure	Facilitate Accessibility Between Communities
Link 1	0.2	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Link 2	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Link 3	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Link 4	0.2	0.0	0.0	0.1	0.1	0.0	0.6	0.0
Link 5	0.1	0.0	0.0	0.5	0.4	0.0	0.0	0.0
Link 6	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Link 7	0.5	0.2	0.0	0.3	0.0	0.0	0.0	0.0
Link 8	0.2	0.0	0.8	0.0	0.0	0.0	0.0	0.0
Link 9	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.4
Link 10	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Link 11	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Link 12	0.2	0.0	0.0	0.0	0.4	0.0	0.4	0.0
Link 13	0.0	0.0	0.0	0.2	0.0	0.5	0.3	0.0
Link 14	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Airport	0.2	0.0	0.0	0.0	0.0	0.5	0.3	0.0

Using the total number of resources deployed to each road link during the simulation and the weighting system defined in Table 4-5, we calculated the proportion of resources contributing to all eight response objectives according to Equation 4-3.

$$CR_i = \sum_{j=1}^{n} (R_j \cdot W_{ij}) \quad \textbf{(4-3)}$$

Where: CR_i – Contributing resources;
i – response objectives;
j – road links plus airport (Table 4-5);
R_j – Total number of resources deployed to each link;
W_{ij} – Weight for each pair Link / Response Objective (Table 4-5);
$1 \leq i \leq 8$;
$1 \leq j \leq 15$.

CR_i results were plotted as shown in Figure 4-8. The graph points to the fact that Response Planning is indeed taken into consideration when making decisions (i.e. deploying resources in the specific case of the game simulation), as resource deployment is similarly proportional to the priorities extracted from Importance Matrices. It also confirms the naturalistic tendencies of emergency management decision-making. Thus, expertise and experience play fundamental roles in the decision-making processes, given that participants did not have access to the weighting system proposed in Table 4-5. In light of this, we conclude that decisions were based on personal estimations (experience and expertise) of the potential benefits. This way, the decision maker aims at achieving the priorities established in the beginning of the simulation through his/her resource deployment strategy.

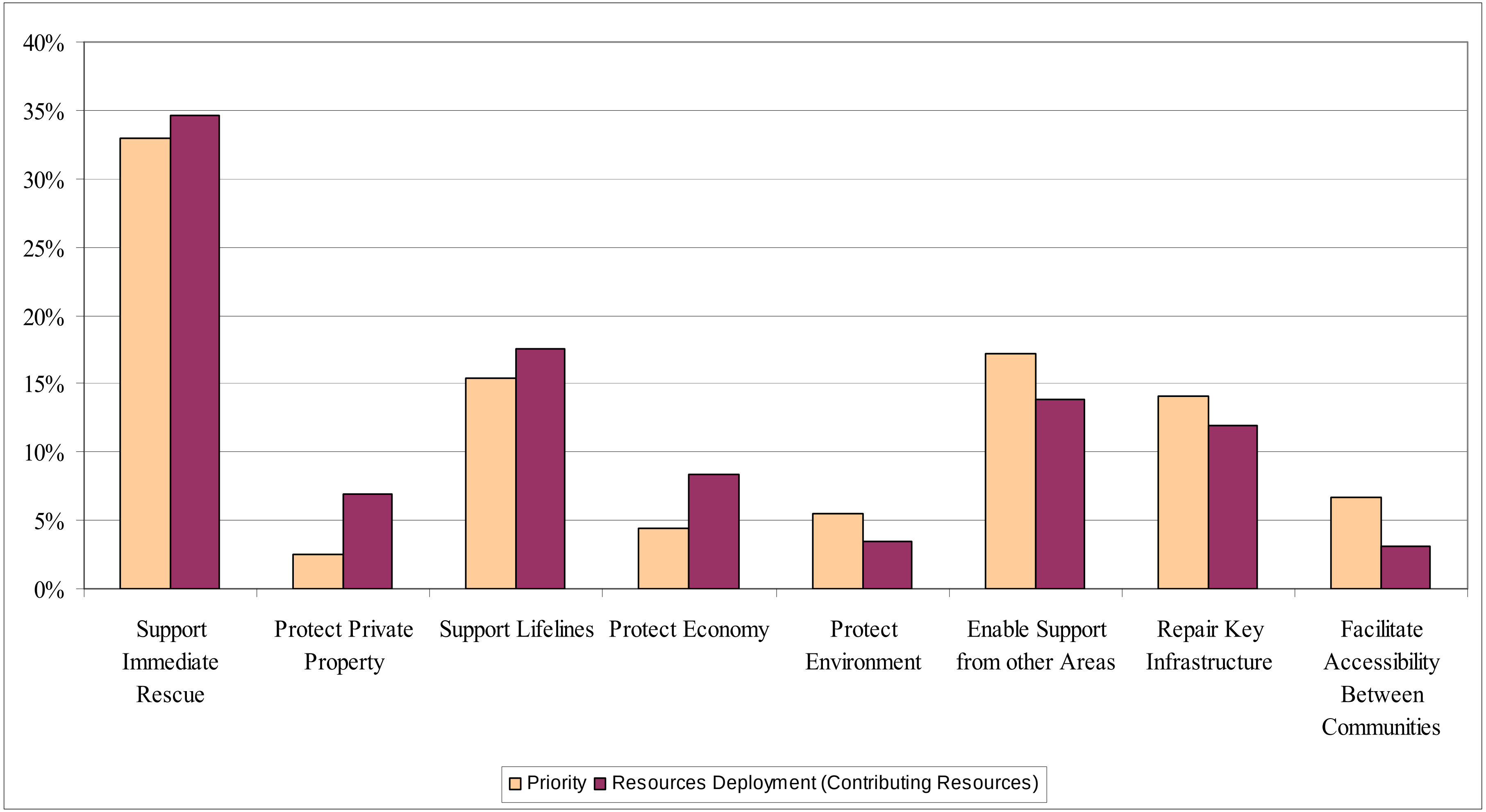


Figure 4-8: Response Planning and Resource Deployment.

Additional to the finding that response planning is considered carefully when making decisions, we also identified distinctions between short term and long term responses. Following on from the principles identified when analysing response planning (e.g. search and rescue activities have to be performed quickly and effectively due to human surviving time spans; critical systems can be re-established after a few days due to provisional resources), we have combined certain response objectives in order to find time dependent response patterns.

Figure 4-9 presents the patterns for both short and long term objectives. Short term responses accounted for "Immediate Rescue" and "External Support" and long term for the remaining six categories presented in the Importance Matrix. Moreover, short term responses have decreasing priorities, while long term ones present an increasing prioritisation. This fact was observed by noting the proportion of resources deployed to each class over time. Note two discontinuity points on the second and third response days, when lifeline support and the repair of key infrastructure are each considered to be immediate needs (or short term objectives) due to the specific game scenario. In these instances, the "flexibility component" that exists for medium priority response objectives plays a role and priorities are adjusted using the decision-maker's improvisation skills. Ultimately, the main response core is maintained and priorities are re-balanced to normal planning levels as soon as the unforeseen situations are handled.

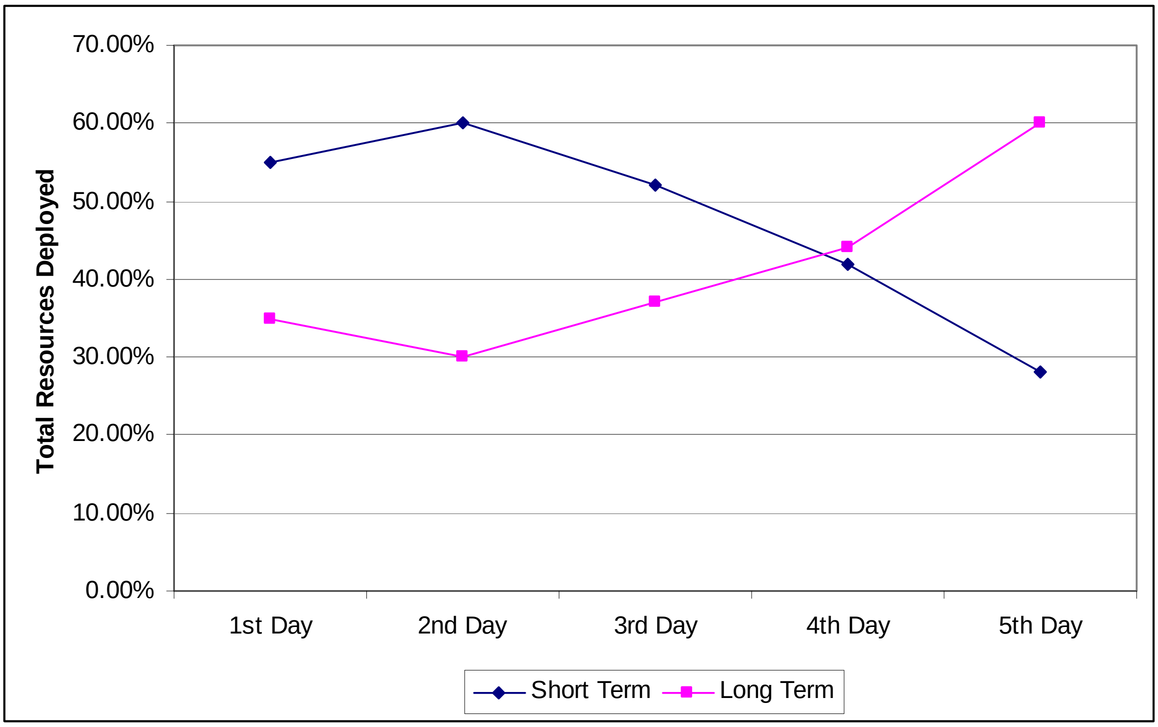


Figure 4-9: General Response Pattern.

- 3rd Phase –Results:

The authors define decision-making as a series of actions that bring about changes to the environment or management processes. The analyses conducted indicated that extreme events decision-making is a function of response planning as events unfold. Although the data collected and the analysis method could not support the creation of a model for extreme events decision-making, the general findings with regards to the decision-making process applied by game participants can be summarised as follows:

1st Finding: Response planning and actual decision-making (i.e. resources deployment) match. Priorities extracted from the Importance Matrix are followed during the simulation, as decisions prioritised objectives according to their respective importance. This fact confirms the rational decision-making process presented in the scientific literature as the Naturalistic Decision Model, in which expertise/experience, knowledge/memory and improvisation all play vital roles;

2nd Finding: 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 “External Support”. Recovery broadens emergency management into longer timeframes with ongoing and escalating efforts, e.g. a bridge repair requires consistent operations over a period of a few months at least;

3rd Finding: Two response objectives are shown to be flexibly arranged in order to cope with unforeseen events. For instance, lifeline support and key infrastructures were highly prioritised at a specific response stage so the loss of power supply and the collapse of a key road bridge could be avoided. Such prioritisation effort was only possible due to resources been redirected from the major response objective defined by most participants (i.e. support immediate rescue); and

4th Finding: Road networks are confirmed to be service providers to communities, critical systems, government and etc. Therefore, road network organisations shall ideally meet external needs according to the specific event’s circumstances.

5 DYNAMIC RESPONSE RECOVERY TOOL

This chapter presents the conceptual development of the Dynamic Response Recovery Tool (DRRT). Following a specific development method, we define the DRRT's framework and its logistics modelling routines. In the Emergency Management (EM) context, DRRT is considered to be a logistics sub-system. It is designed for roading organisations and made up of traditional logistics concepts (e.g. players, systems, distribution channels, cost functions) and lessons learned from the observation and simulation of emergencies.

The chapter is divided into three sections. Initially, we explain the context in which the DRRT was designed. The second section describes the DRRT development method. The final section comprehensively describes the DRRT system, specifying its operational components (e.g. knowledge base, inference engine and graphical user interface) and its logistics tools (i.e. players' identification, system conceptualisation, distribution channel configuration, total cost formulation and minimisation routines).

5.1 DRRT Context

The DRRT is conceptualised as a logistics sub-system as part of Disaster Management – a sub-topic of EM itself. During a disaster, the DRRT facilitates decision-making by mobilising response organisations and deploying human and physical resources. These are considered to be typical logistics activities, which in the specific context of EM save lives, restore businesses and reduce the economic impact of disaster situations. Overall, they are part of the continuous efforts made to try to better achieve numerous organisations' goals during disasters, according to the specific situations and resource availability/need. Decision support reaches its goals when efficient and accurate information is provided to end users so that decisions can be continuously made until a stable state of "normality" is reached. The DRRT is linked to the wider process of Reduction, Readiness, Response and Recovery defined by the Ministry of Civil Defence and Emergency Management in New Zealand (MCDEM, 2009).

In particular, DRRT is geared towards supporting response and recovery activities by providing:

- **Procedural recommendations:** a group of recommendations for effective and efficient organisational arrangement and response management. It comprises a series of guidelines that support the decision-making process with regards to communication set up, information sharing procedures, physical assessments of affected infrastructures, response prioritisation, etc; and
- **Physical resource deployment recommendations:** these are intended to compliment the procedural recommendations. Optimisation routines were designed in order to facilitate resource allocation. Logistics concepts (e.g. total cost minimisation, distribution channels, players) and a GIS Platform were used to develop and deploy an optimisation routine that helps to minimise the total cost of response and to reduce the overall economic impact of disasters.

In summary, the DRRT provides response recommendations regarding disaster management and suggests optimum strategies for deploying resources from their origins (availability) to the desired destinations (required locations). It is expected that the available resources will meet organisations' needs if they adhere to the previously agreed upon optimum schedules and costs. The goal of this is for "normality" to be restored as soon as is practical. A schematic representation of the logistics environment in which the DRRT operates is illustrated in Figure 5-1. Three main components are considered in the quest to provide good levels of decision support during emergencies: i) participating parties; ii) data input and iii) support systems. These three components, if managed well, are expected to provide the information needed to the three existing logistics mechanisms within the DRRT system (described as follows):

- **Resource Needs:** gear and materials needed to conduct repair and reconstruction efforts. Estimations of the resources needed (types and quantities) are based on previous studies or field assessments conducted immediately after the event;

- **Resource Availability:** available resources from both public and private organisations as well as international aid agencies (i.e. resources to be promptly deployed to disaster zones); and
- **Damage Location:** specific geo-spatial information about physical damage to the numerous systems affected (e.g. road, sewage, power, telecommunications) within disaster zones.

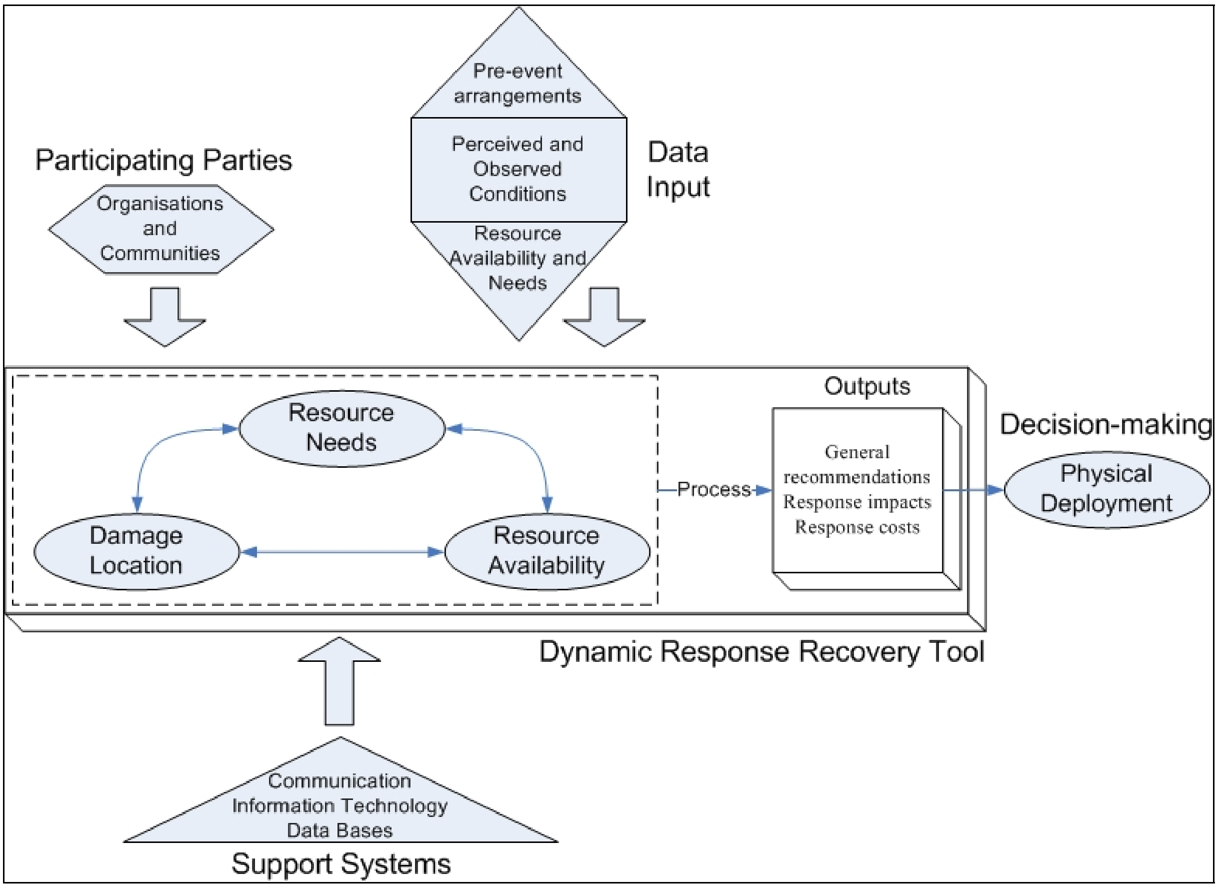


Figure 5-1: Conceptual DRRT Environment.

Ultimately, physical deployment must take into account the complex set of information generated by the three abovementioned logistics mechanisms. These comprise the actual decision-making processes regarding the distribution of resources according to priorities, needs, availability and asset damage patterns in a holistic approach.

On practical grounds, the DRRT's procedural level refers to management processes and protocols such as communication, information sharing and prioritisation. These are the outcomes of the complex and interrelated relationships among staff and organisations. Given that it is difficult to model these according to engineering paradigms, they were identified and recorded by observing organisations and communities during real or simulated emergencies as well as studying contingency, business continuity and response plans. Finally, optimisation routines aim to support the physical deployment of the resources and personnel needed to meet organisations' needs (according to resource availability). Hence, data processed by logistics tools (e.g. shortest path, total cost minimisation) are expected to facilitate the decision-making processes by maximising response efforts.

5.2 DRRT Development Method

The DRRT system development method is made up of five phases: i) define requirements, ii) design, iii) implementation, iv) verification and v) maintenance. Initially, the DRRT system's requirements, such as field of application, data input formats, information needs and logistics tools, were defined. Subsequently, the conceptual components of the DRRT as a decision support system were designed, e.g. Knowledge Base, Inference Engine, Modelling Routines and Graphical User Interface. The implementation phase involves envisaging, planning, developing and testing the Information Technology solution. After the IT Solution is implemented, it needs to be tested (i.e. verified) according to design parameters and its actual performance. Thus, real case studies need to be conducted in order to assess how end users are likely to perform while operating the system and how operational and technical shortcomings can be addressed. In this way, a final system version can be compiled and maintenance protocols can be defined. This process would aim to both maintain the system at acceptable operational levels and identify any shortcomings, so that updated versions can be more robust and can better attend users' needs.

5.3 DRRT System

This section reports the development activities performed for phases one and two from the DRRT Development Method. Initially, the DRRT system's requirements were set up in line with the traditional concepts presented in section 5.1. Following that, the DRRT's logistical components and its optimisation algorithm are described.

5.3.1 Procedural DRRT: A Decision Support Tool for Emergency Response Operations within Roading Organisations

The DRRT system was schematically designed (Figure 5-2) based on an adaptation of Berkes *et al.* (2001)'s Expert System model, lessons learned from exercise observations and game simulations, and logistics concepts. Note that the DRRT's Knowledge Base receives data from the emergency environment and can also be adapted by Participating Parties if there are changes in priorities and response needs over time. Data is collected using Support Systems such as communication technologies, GIS and infrastructure assessment frameworks that ultimately represent emergency situations and resource needs/availability. These data are further filtered, accordingly to specific information needs, before being processed along with other inputs from communities and organisations. The process takes place at the Inference Engine, which also uses previous decisions made to recommend decision-making solutions (which are prompted in a user friendly interface).

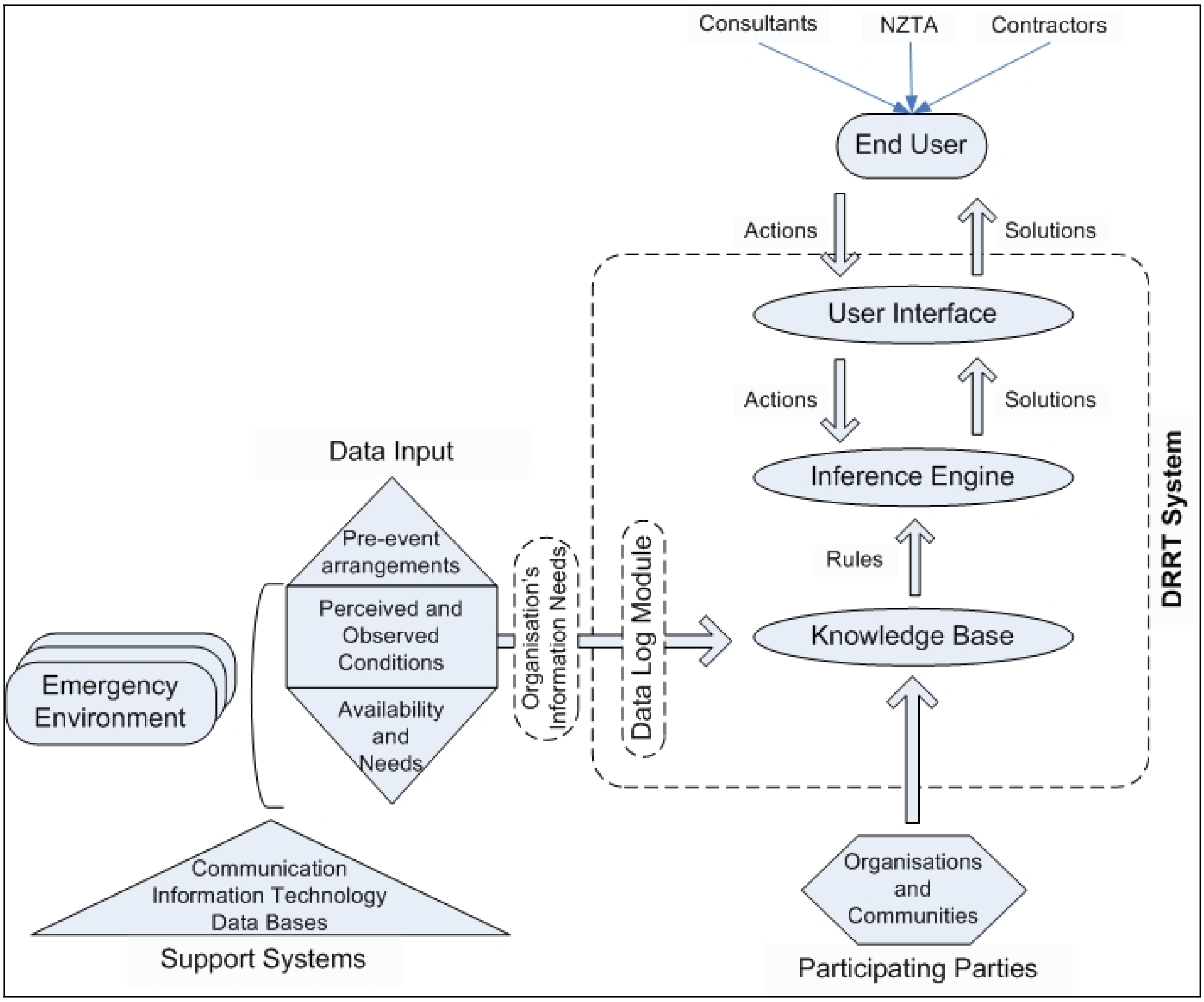


Figure 5-2: DRRT System.

Berkes *et al.* (2001)'s model configures the main core of the DRRT System, i.e. operational links between the Data Input, Knowledge Base, Inference Engine and User Interface. As described in the Literature Review, the Knowledge Base involves a set of rules used to process external inputs and generate information. Data processing takes place in the Inference Engine, which contains an operational algorithm that compares external inputs with the available knowledge (i.e. rules) in order to find appropriate solutions. Finally, a User Interface presents both external inputs and solutions (or outputs) in easy formats to facilitate decision-making. Note that the Knowledge Base (KB) is fed by general data and the Participating Parties, which represent the real time emergency environment and community/organisations' needs, respectively.

In principle, the KB is static, meaning rules cannot be changed over the course of the event, but only have greater or smaller importance as the event unfolds. Nonetheless, findings from individual emergencies can be further incorporated into the KB by creating new rules. Hence, the system becomes more robust over time as new lessons are learned so that decision-making can be better supported. Finally, Support Systems (e.g. communication, Information Technology) capture data about Perceived and Observed Conditions as well as Resource Availability and Needs. These data are filtered by a human operator, according to individual organisations' needs, and finally logged into the DRRT System.

The vital DRRT System components are described as follows:

- **Data Log Module:** this links the emergency environment and the Knowledge Base. Along with a human operator, it is responsible for filtering the incoming data according to individual organisations' needs and system data formats;
- **Knowledge Base (KB):** this is the component that contains the set of operational rules and optimisation routines used to process data into decision-making support information;
- **Inference Engine (IE):** this is the computational component, which is responsible for running search and/or optimisation algorithms to process incoming data. For the first of these, the IE identifies rules (according to data fed into the system) that provide procedural response recommendations to the end-user. In the latter case, an algorithm is used to identify optimum resource deployment strategies according to resource availability and needs; and
- **User Interface:** a graphical interface that presents incoming data and outcomes (e.g. recommendations, resource deployment strategy) to end-users in customised formats in order to support/facilitate decision-making.

Operationally, the DRRT System processes external data according to two sub-sets of "knowledge", i.e. Operations Decision-making and Resource Allocation Optimisation Tools. Both categories provide recommendations/information to end-users in the form of either decision-making processes or optimum logistics operations for resource allocation. Figure 5-3 illustrates this process, which is finalised by presenting information in an appropriate graphical interface to make it easy to visualise.

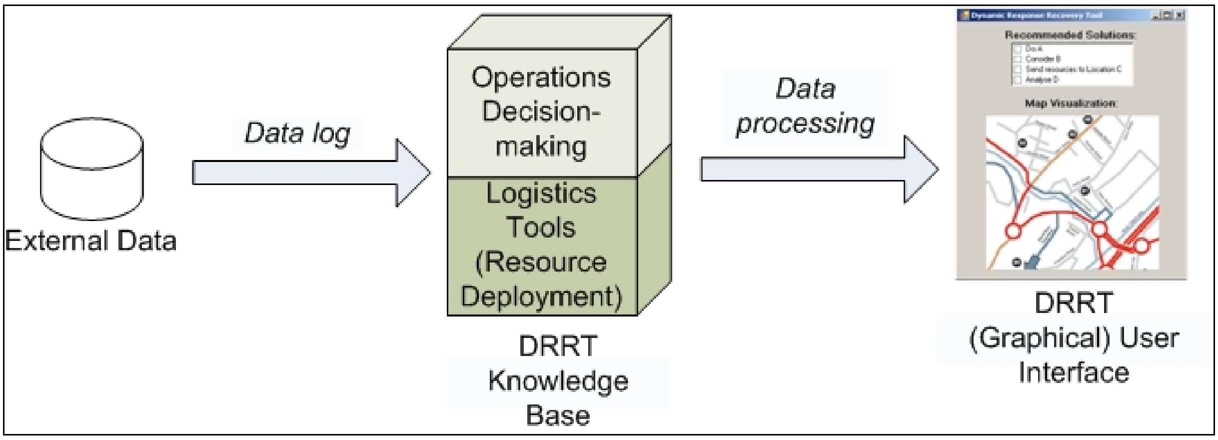


Figure 5-3: Operational DRRT.

In terms of supporting decision-making operations, the DRRT System is designed to operate according to binary codes. Thus, external data is coded and compared with knowledge (i.e. rules) recorded within the KB. When matching codes are found, recommended solutions are withdrawn from the KB and presented to the end-user. Figure 5-4 is an example of this process. For instance, consider that external data was coded as patterns 0001, 0101, 1010 and 1001. When searching the KB/Operations Decision-making sub set, the Inference Engine identifies two matching patterns: 0001-x and 1010-x. These patterns are extracted from the KB, decoded and entered into the DRRT's User Interface as recommendations (e.g. "Check landline, cell phone, Satellite phone, RTs, internet and e-mail services", "Run test calls for confirmed operational technologies", "Arrange EOC", "Assign management positions"). Note that the code "x" in the Knowledge Base indicates a series of recommended action contained in a major category, e.g. communication.

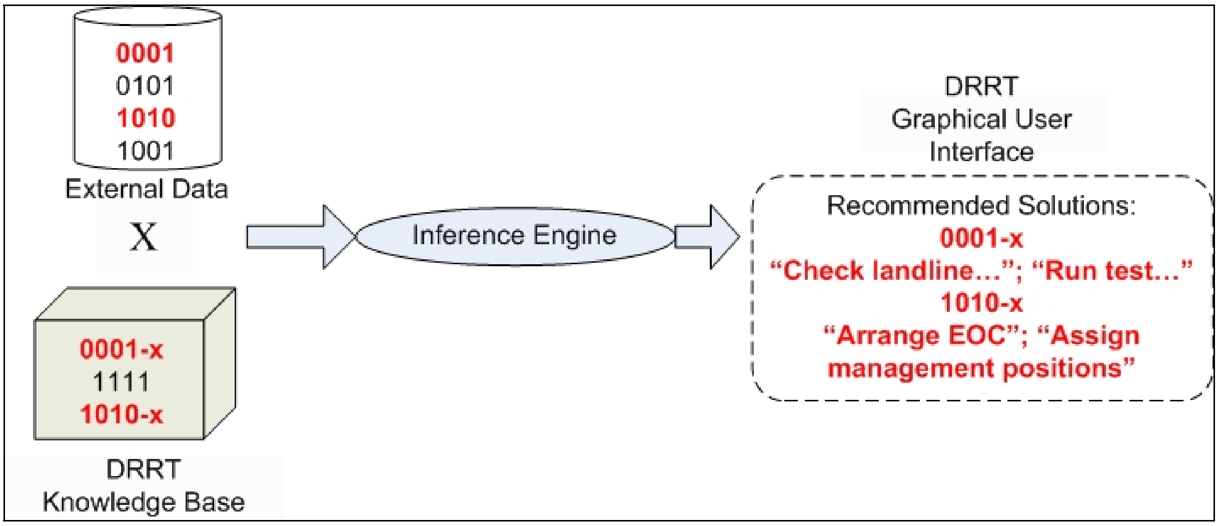


Figure 5-4: Expected DRRT Inference Engine Process.

The complimentary KB sub-set (i.e. Logistics Tools) is presented in the following sub-section. These logistics and resource allocation tools are proposed to facilitate decision-making. They do this by identifying the optimum deployment strategies according to the level of damage to the road network.

5.3.2 DRRT Logistics Environment: Tools for Optimising Resource Allocation

Logistics problems are usually solved using a three step process: i) gathering as much information as possible about the problem; ii) defining logistics systems and cost functions; and iii) developing mathematical optimisation routines (Daganzo, 2005).

In accordance with this process, information was collected about how organisations and communities respond during emergency events (gleaned from exercises and real event observations). The information gathered was specifically related to how physical resources are deployed (according to availability, needs and priorities) during disasters – and game simulations. This process helped us to understand the complex management environment in which disaster response and recovery activities take place.

Using this background knowledge in EM we identified the logistics problem faced when searching for optimum resource allocation strategies. Thus, a complete analysis the logistics problem faced by roading organisations when deploying physical resources requires defining a logistics system as well as proposing an appropriate mathematical approach. These activities are described as follows.

5.3.2.1 Logistics Systems

Although human response can heavily impact the performance of logistics systems during emergency management, the model proposed in this thesis focuses in defining the physical environment in which resource prioritisation and deployment takes place. In this context, three distribution channels were defined: i) Resource Depot (*RD*), ii) Resource Availability Location (*A*) and iii) Resource Demand Location (*R*). Both "*RD*" and "*A*" represent locations where resources are available, either at depot(s) or on the field due to maintenance, repair or construction works. Additionally, the distribution channel "*R*" represents damaged asset locations that need to be repaired. In this context, two scenarios are likely to occur, namely i) Direct Resource Allocation or ii) Indirect Resource Allocation. In the first scenario, resources are deployed non-stop from depot(s) to points of need (required locations). Machinery is shifted directly from its origin to its destination; loading activities are not required given that all necessary physical and human resources (e.g. drivers, fuel, materials) are available at the depot(s). The second deployment scenario involves resources being available at numerous locations throughout a region, rather than just at depots. In this scenario machinery is used for construction or maintenance operations that can sometimes be scattered across a region. In this respect, resources can be deployed to required destinations as an emergency response either non-stop (considering that all material and labouring needs are already available) or with a stop at the depot(s) to load materials or collect additional personnel. Based on observations of real emergency events (e.g. the 1994 Northridge Earthquake - USA, the 1995 Kobe Earthquake - Japan, the 2004 Sumatra Earthquake and Tsunami - Asia, and the 2005 Hurricane Katrina - USA), the second scenario is the most likely one to occur during disasters.

The logistics theory indicates four possible types of situations i) one origin and one destination; ii) one origin and many destinations; iii) many origins and one destination and iv) many origins and many destinations. The study of (previously mentioned) recent disasters and the observation and simulation of emergency exercises as reported by Ferreira *et al.* (2010a, 2010b, 2010c) and Giovinazzi *et al.* (2008) strongly indicate that only the last two situations are likely to occur during an emergency. This is due to the probable fact that resources are available at multiple locations and might be required either at a single location (e.g. fire event, flash flood, traffic accident) or at multiple locations (e.g. earthquake, volcanic eruption, tsunami). Finally, the number of Resource Depot channels (RD) depends on specific environment configurations (e.g. number of contractors, existing management systems, affected area). Figure 5-5 illustrates these possible logistics system configurations.

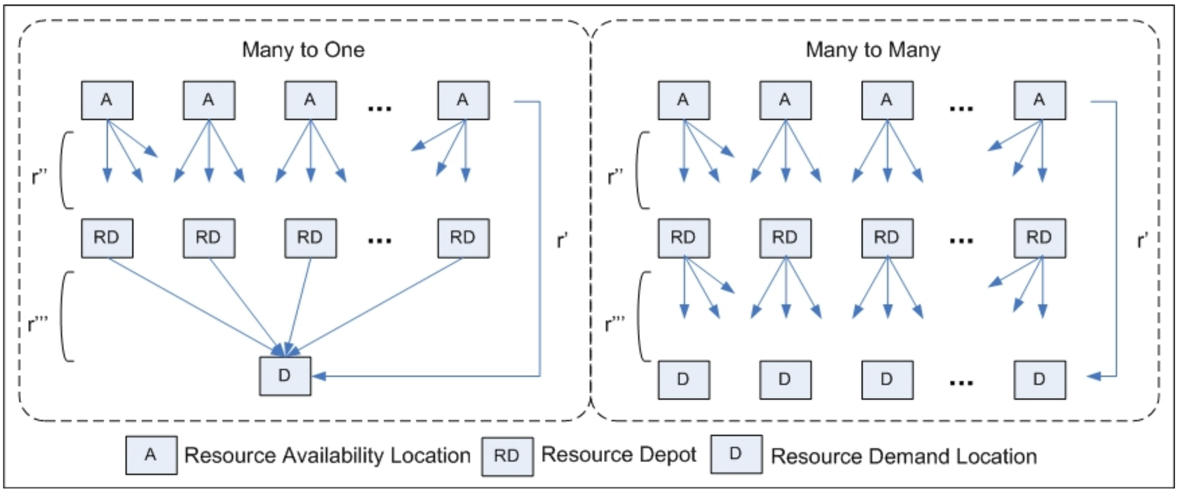


Figure 5-5: Logistics Systems and Problems in Disasters Situations.

Finally, as previously described, resources can be deployed directly from available locations to final destinations (e.g. depot to required location: r''', or available location on field to required location: r') or with a stop at a depot distribution channel – *RD*, i.e. from available location on field to required location with a stop at depot: r'' + r'''. Such deployment strategies are modelled in the next sub-section using a mathematical description of cost functions. An optimisation routine is proposed to identify the optimum resource deployment strategies in a complex disaster environment.

5.3.2.2 Logistics Problem Statement and Optimisation Model Design

Consider an organisation performing response activities immediately after an extreme event that has affected an area of analysis and its road transport network. Roading organisations can deploy the total available resources at any given time t (R^t) located at any location i such as R_1^t, R_2^t, R_3^t, ...R_i^t... R_n^t to support response efforts (asset damage repair, rescue operations, evacuation management, lifeline support, etc.) at any damaged location j such as D_1^t, D_2^t, D_3^t, ...D_j^t ... D_m^t. Resource deployment is further subject to a set of priorities P^t assigned to each response effort such as P_1^t, P_2^t, P_3^t, ... P_k^t. Thus, set of resources with origin i and destination j (r_{ij}^t) are allocated to damaged locations individually in order to support response efforts.

A resource optimisation routine is defined around two cost components, namely Logistics Response Cost (*LRC*) and Delay Response Cost (*DRC*). The Total Response Cost (*TRC*) involves the *LRC* and the *DRC*, which is minimised subject to a set of conditions under the decision makers' control. The remainder of this sub-section presents the *LRC*, the *DRC* and the *TRC* minimisation approach.

Logistics Response Cost (*LRC*)

LRC is the travel cost plus the loading and unloading costs. As defined in Equation 5.1, travel costs are directly proportional to allocated resources (r_{ij}^t) and travel distance. Loading/unloading costs are only dependent on the volume of allocated resources.

$$LRC(R^t) = r_{ij} * [(td_{ij} * \alpha) + (LT + UT) * \beta] \qquad \textbf{(5-1)}$$

Where: r_{ij}: allocated resources from origin i to destination j

td_{ij}: travel distance from i to j

α: unitary travel cost (cost per distance)

LT: Loading time (average time taken to load one resource unit with necessary materials and fuelling time)

UT: Unloading time (average time taken to unload materials transported by one resource unit)

β: unitary loading / unloading cost (cost per time)

Note that the travel distance (td_{ij}) relates to the sum of the link lengths in the shortest path between an origin i and a destination j (Pt_{ij}). Furthermore, for a given time t (with Loading Time being equal to Unloading Time for the sake of simplification) we have:

$$LRC^t = \sum_i \sum_j ((r_{ij}{}^t * td_{ij} * \alpha) + (r_{ij}{}^t * (LC + LC) * \beta)) \quad \textbf{(5-2)}$$

Simplifying Equation 5.2 and Equation 5.3 which represents the Logistics Response Cost for any given time t.

$$LRC^t = \sum_i \sum_j (r_{ij}{}^t * (td_{ij} * \alpha + 2LC * \beta)) \quad \textbf{(5-3)}$$

$$\text{Given: } td_{ij} = \sum_{a \in Pt_{ij}} L_l{}^a$$

Where: $r_{ij}{}^t$: allocated resources from origin i to destination j at time t
td_{ij}: travel distance from i to j
α: unitary travel cost (cost per distance)
LC: Logistics cost (total time for loading and unloading)
β: unitary loading / unloading cost (cost per time)
Pt_{ij}: Minimum path between an origin i to a destination j
$L_l{}^a$: Length value for a link belonging to the minimum path Pt_{ij}

Delay Response Cost (DRC)

The *DRC* represents the fixed asset repair cost plus the costs incurred when vehicles are unable to travel on a given link due to decreased road capacity. Equation 5.4 generalises the *DRC* at any given time t.

$$DRC^t(R^t) = \sum RC_l + \sum CD_l{}^t[r_{ij}{}^t, D_j^t] * \frac{1}{\sum_j \sum_k \delta_{jk}{}^t} \quad \textbf{(5-4)}$$

Where: *DRC:* Delay Response Cost
R^t: Available Resources at time t
RC_l: Link repair cost
$CD_l{}^t$: Cost of delay for link l at time t
$r_{ij}{}^t$: allocated resources from origin i to destination j at time t
$D_j{}^t$: Damage at destination j at time t (affected road asset)
$\delta_{jk}{}^t$: Adjustment factor for Cost of Delay ($CD_l{}^t$)

Note that delay cost is a function of allocated resources ($r_{ij}{}^t$) and experienced damage ($D_j{}^t$), as repairs occur according to the number of resources available at extend of damage at each location. *DRC* is finally given by the Cost of Repair (RC_l) plus the Cost of Delay ($CD_l{}^t$) for all damaged links at destinations j times the inverse factor $\delta_{jk}{}^t$. The factor $\delta_{jk}{}^t$ considers the response priorities ($P_k{}^t$), as extreme events decision-making has revealed itself to be a naturalistic decision process. As well, $CD_l{}^t$ alone should not be considered the sole variable in extreme events decision-making (Ferreira *et al.*, 2010a and Ferreira *et al.*, 2010b and Ferreira *et al.*, 2010c). Furthermore, $\delta_{jk}{}^t$ expresses the directly proportional relationship between response objectives and the network. This is the reason why its inverse function needs to be considered, i.e. the greater the relationship response planning/road network links, the less it costs to deploy resources to damaged locations. In this light, *DRC* is specified using the following Equation 5.5. Observe that cost of delay will be null if the remaining link capacity ($C_l * (1 - D_j^t)$) is greater than the link flow. In such case, there is no congestion so road users are not delayed and costs are not incurred. On the contrary, there will be delay costs if link flow exceeds link capacity and therefore generate congestion.

$$CD_l^t = \begin{cases} 0 & \text{if } F_l - C_l * (1 - D_j^t) \le 0 \\ (F_l - C_l * (1 - D_j^t)) * \theta & \text{if } F_l - C_l * (1 - D_j^t) > 0 \end{cases} \qquad \textbf{(5-5)}$$

$$\text{Given: } 0 \le D_j^t \le 1.0$$

Where: $CD_l{}^t$: Cost of delay for link l at time t
F_l: Link flow
C_l: Link capacity
D_j^t: Damage at destination j at time t (affected road asset)
θ: unitary cost of delay per vehicle

Finally, *DRC* is given by Equation 5.6.

$$DRC^t\left(R^t\right) = \sum RC_l + \sum (F_l - C_l * (1 - D_j^t)) * \theta * \frac{1}{\sum_j \sum_k \delta_{jk}{}^t} \qquad \textbf{(5-6)}$$

Where: $CD_l{}^t$: Cost of delay for link l at time t
RC_l: Link repair cost
F_l: Link flow
C_l: Link capacity
$D_j{}^t$: Damage at destination j at time t (affected road asset)
θ: unitary cost of delay per vehicle
$\delta_{jk}{}^t$: Adjustment factor for Cost of delay ($CD_l{}^t$)

Total Cost

The *TRC* is the sum of *LRC* and the *DRC*. *TRC* is found by calculating the sum of *LRC* and *DRC* for all times t as presented in Equation 5.7. Thus, an organisation's staff will attempt to allocate specific sets of resources r_{ij}^t in order to minimise the *TRC*. This contributes to the overall response and recovery efforts to minimise loss of life and economic disruptions. The total response cost minimisation routine (or resource allocation optimisation routine) is specified below, along with its conditions.

$$TRC = \sum_t LRC^t + \sum_t DRC^t \tag{5-7}$$

5.3.2.3 Resource Allocation Optimisation Routine

An organisation's staff will attempt to allocate specific sets of resources r_{ij}^t in order to minimise the *TRC*. To this end, they need to identify the best resource deployment strategy. This optimisation process is represented by the minimisation of *TRC* as shown in Equation 5.8, subject to the set of conditions proposed. It ultimately expresses the overall contribution of response and recovery efforts towards minimising loss of life and everyday disruptions.

$$\min(\sum_t TRC^t) = \min(\sum_t (LRC^t + DRC^t))$$

$$\min(\sum_t ([\sum_i \sum_j (r_{ij}{}^t (td_{ij} \cdot \alpha + 2LC \cdot \beta))]^t + [\sum RC_l + \sum (\frac{F_l - C_l \cdot (1 - D_j^t)) \cdot \theta}{\sum_j \sum_k \delta_{jk}{}^t})]^t)) \tag{5-8}$$

Subject to:

$\sum_i \sum_j r_{ij}^t = R^t$	Sum of resources deployed at t^{th} time from origin i to destination j - r_{ij} - shall be equal the total available resources at t^{th} time - R^t
$td_{ij} = \sum_{a \in Pt_{ij}} L_l^a$	Travel distance from origin i to destination j is the sum of link lengths L_l for the minimum path Pt_{ij}
$\sum_k P_k^t = 100$	Sum of priorities for k response objectives at a given time t shall be equal to 100 (i.e. 100%)

The process described by Equation 5-8 and its optimisation conditions is ultimately implemented by estimating *LRC*, *DRC* and *TRC* for all possible resource deployment strategies. This involves estimating all the different combinations of resource assignments to all the possible origin/destination sets.

Results are to be presented in the user-friendly interface designed for the DRRT System. The next chapter presents the application of the DRRT concept to a series of case studies in order to assess the system's efficiency, as well as how suitable it is to facilitate decision-making within roading organisations during emergency events.

6 DRRT CASE STUDY

A set of case studies is presented in this chapter in order to assess the DRRT's efficiency and suitability for SHO. By simulating an emergency scenario, DRRT was evaluated in its potentialities to facilitate decision-making during extreme events. We aimed at identifying whether participants using decision support information had better performance than those disregarding DRRT's functions such as recommended actions, general maps, GIS maps and resource deployment recommendations.

The case study application was developed taking into consideration the findings from exercise and real events observations (chapter 3), game based scenario simulations (chapter 4) and the DRRT system and resource allocation logistics model proposed in chapter 5. Participants were invited from both academia and industry in order to support an extensive data collection and analysis. The case study application was focused on the specific context of New Zealand SHO and emergency practices in currently use in the country.

The chapter is divided into three major sections: DRRT Implementation, DRRT Case Studies and Results of the DRRT Experiment. The first section presents how an IT solution application was developed in order to run the case studies (i.e. emergency scenario, data collection routines, DRRT's operations simulations). The case study set up, scenario specification, data collection procedure, data analysis method and simulation process are presented in the second section. The third and final section scrutinizes the information gathered during the case studies so major findings regarding DRRT's decision support capability and applicability during real emergencies in the context of RCAs could be discussed.

6.1 DRRT Implementation

The DRRT application was developed accordingly to the Implementation Phase proposed in the section 5.2. Hence, three main activities were performed, namely IT Solution Framework design, System Design Protocols specification and Case Study Application development. Each one of these activities is further described with sufficient details to clearly report the development and deployment of the case study application.

6.1.1 IT Solution Framework

Basic principles from the Microsoft Solution Framework® (MSF) were used to support the development and deployment of the DRRT Case Study Application. The MSF framework comprises five phases: i) Envisaging the Solution; ii) Planning the Solution; iii) Developing the Solution; iv) Testing the Solution and v) Deploying the Solution. All these phases are briefly discussed in this sub-section for the specific case of the DRRT. We only intend to lay down simple conceptual IT paradigms to support an easy comprehension of how the application was planned, developed and deployed.

Following the initial phase proposed by the MSF, we envisaged the DRRT IT Solution as a prototype software. We aimed at a semi-operational application to demonstrate in a limited extent the DRRT's functions. The application was designed to be operational at both Windows® and Linux® Operational Systems (OS) in order to avoid compatibility issues as well as be flexible enough to allow uploading different emergency scenarios.

The planning stage accounted for defining the system's information flow configuration, specifying data needs and running processes. Figure 6-1 schematically represents the basic DRRT demonstrator structure. Application data (or emergency scenario data) feeds a Graphical User Interface (GUI), which also serves for data log and collection. Application data are also presented by pop up windows (e.g. maps, situation reports) and dialog windows allow the end user to log specific information. The emergency scenario is simulated by a serial step process, in which decisions made and associated information are recorded, e.g. action taken, time elapsed, decision performance. The running process was designed so updated situations are presented to the end-user along with the scenario development.

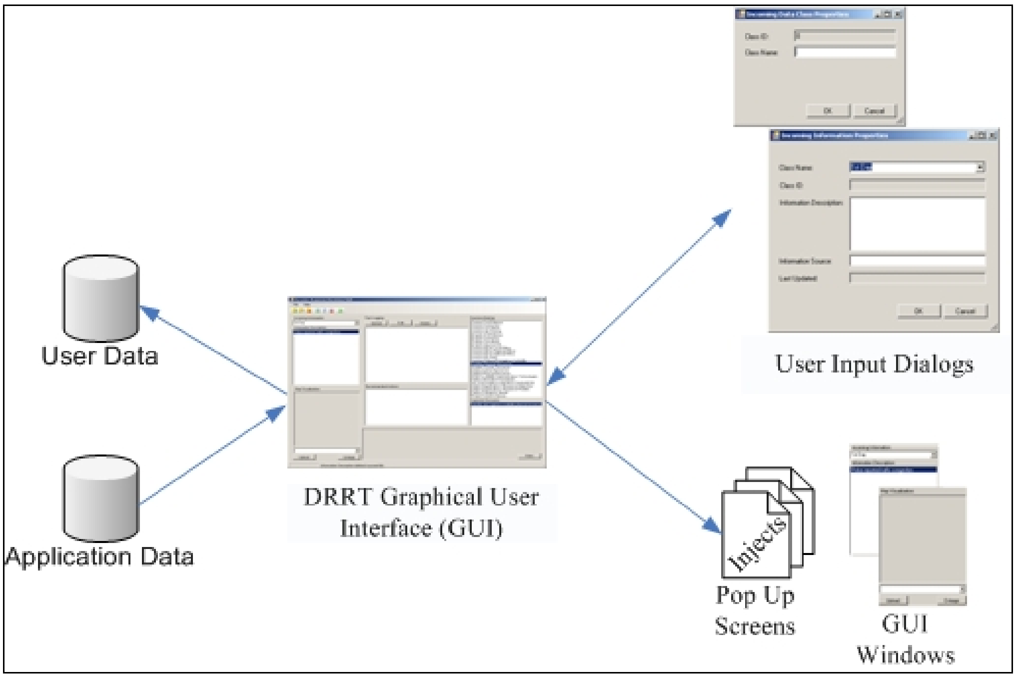


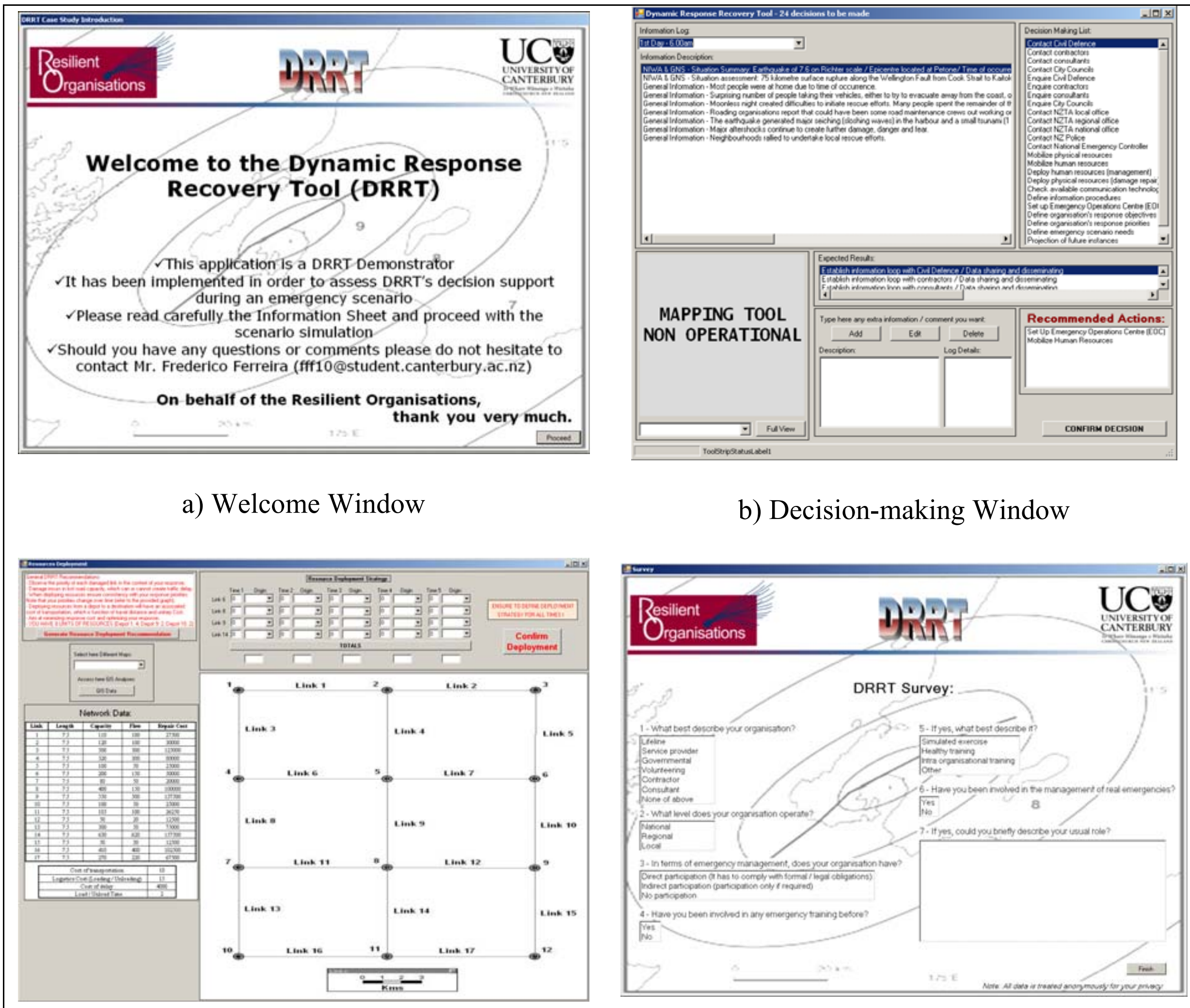
Figure 6-1: DRRT Information Technology Solution Diagram.

Following DRRT specifications defined in the initial two development phases, the DRRT was implemented using the Visual Basic (VB) Programming Language and the Microsoft Visual Studio .NET Framework® development environment. The first DRRT case study application version was deployed after 3 months from its initial planning. A number of pilot tests were performed over a six month period until the final version could be deployed to conduct the case studies. The next sub-section briefly describes the final version as well as presents some snapshots from the proposed application. Very limited technical information is provided in the next sub-section due to the aim of this research and the intended objective of this chapter to assess the DRRT.

6.1.2 DRRT Case Study Application

Windows Forms applications were mostly used to develop a dynamic and comprehensive simulation for an evolving emergency scenario. .NET Framework® and Visual Basic® Programming Language were used to deploy the DRRT IT Solution and embed the intended emergency scenario. The application was flexibly designed so alternative emergency scenarios could be exercised (e.g. volcanic eruption, tsunami warning, flooding).

Figure 6-2 illustrates some of the windows forms designed for the DRRT application. They are snapshots from the welcome window, main decision-making form, resource deployment window and initial survey, respectively. Figure 6-2a presents the user with succinct information about the application as it is intended to use the DRRT Demonstrator in the future for emergency training without the presence of an exercise controller so costs can be reduced. The second window (top right corner) shows the main decision-making environment, in which a series of panels present the user with a complete set of information about the scenario and system's functions. Each of these panels is further described in Figure 6-3. Figure 6-2c represents the resource deployment task required to be performed at a particular stage of the simulation. Note that the user has to fill in the number of resources to be deployed to each damaged link as well as their respective destinations. Decision support information is provided through available GIS Maps and results from a resource optimisation routine as illustrated in Figure 6-4. The last window illustrates a survey conducted to acquire specific information about the participant so data analyses can be performed taking into consideration personal experiences, organisational obligations and etc. Snapshots illustrated in Figure 6-2 superficially illustrate the DRRT Application as a number of additional windows are used to run the simulation (e.g. map views, GIS Data, Decision Summary), but are not shown here for the sake of space.



a) Welcome Window

b) Decision-making Window

c) Resources Deployment Window

d) Survey Window

Figure 6-2: Snapshots from the DRRT Application.

To better present the DRRT Demonstrator, two of its main windows (decision-making and resource deployment) are specified as follows. Before describing these windows, it is important to remember that the DRRT was designed considering two approaches for decision support: i) to provide procedural decision-making recommendations and ii) to identify optimum resource deployment strategies. Both approaches were comprehensively based on the whole research conducted. Thus, findings from the literature review (chapter 2), exercise observations (chapter 3), game simulations (chapter 4) and DRRT conceptualisation/logistics model development (chapter 5) were fully utilised to deploy the DRRT case study application.

Firstly, procedural decision-making was designed to be facilitated by presenting the end-user with a series of recommendations and possible outcomes associated with each decision-making. Figure 6-3 (the main decision-making window) contains a number of different panels, in which the decision support and the scenario information are presented. Each panel is described as follows:

- **Panel #1:** Scenario information presented over time, also known as "scenario injects";
- **Panel #2:** Possible decision-making activities to be chosen;
- **Panel #3:** Brief description of main decision-making activities;
- **Panel #4:** Access to available maps for the affect area and road network. A full view is available by clicking the button "*Full View*";
- **Panel #5:** Presents the user with expected results from individual decision-making activities;
- **Panel #6:** Tool that allows the end-user to log any additional information;
- **Panel #7:** Recommended decision-making actions to support procedural decision-making; and
- **Panel #8:** Button "*See Summary*": opens a summary window containing previous decisions taken and confirmed results; Button "*Confirm Decision*": proceeds with the scenario simulation by confirming the decision selected on Panel #2.

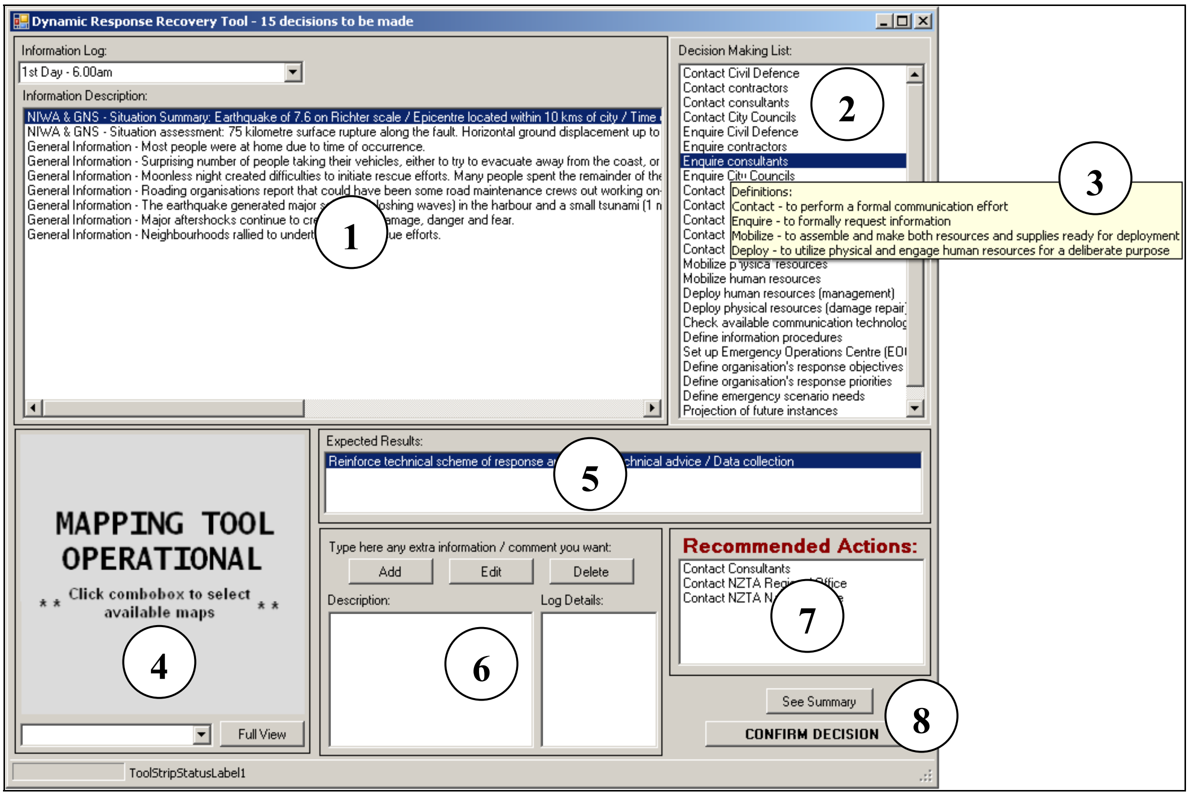


Figure 6-3: DRRT Application Snapshot: Main Decision-making Window.

Secondly, a resource deployment task was designed to collect resource allocation information. This task has been proposed in order to both check the realism of the proposed resource allocation optimisation routine proposed in chapter 5 and to identify ways to better present decision support information to the end-user In this context, a set different supporting information was added into deployment windows according to optimum resource allocation strategies identified using the proposed routine. Costs were estimated for more than 2,900 deployment strategies and the thirty optimum ones were chosen as shown in Appendix E. For the sake of a clear presentation, only the three best strategies and costs were presented to case study participants as illustrated in Figure 6-4. This figure shows both resource deployment window and decision support information as just described.

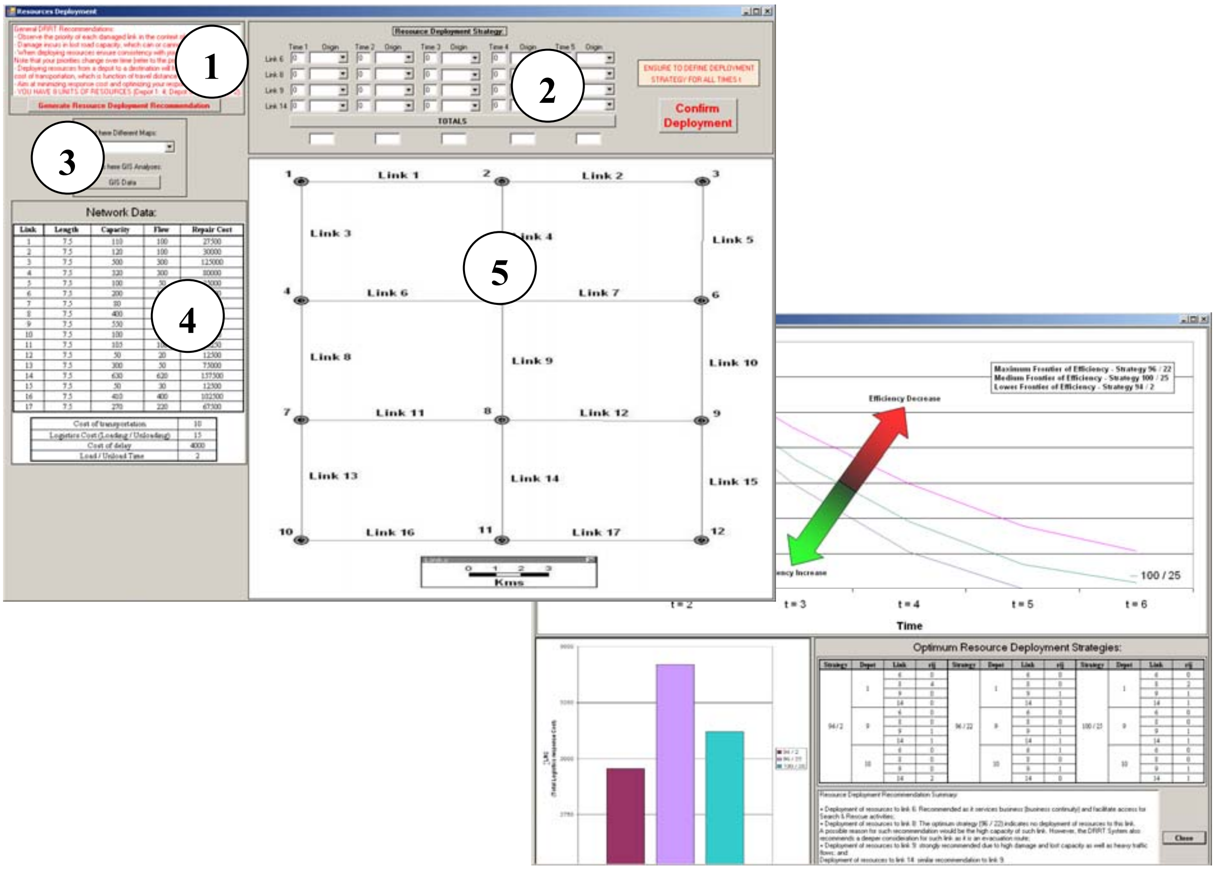


Figure 6-4: DRRT Application Snapshot: Resource Deployment Window and Optimisation Results.

The resource deployment window (top left corner) presents the participant with five panels. Each panel is further described and together they provide supporting information needed to define a resource allocation strategy in order to respond the event.

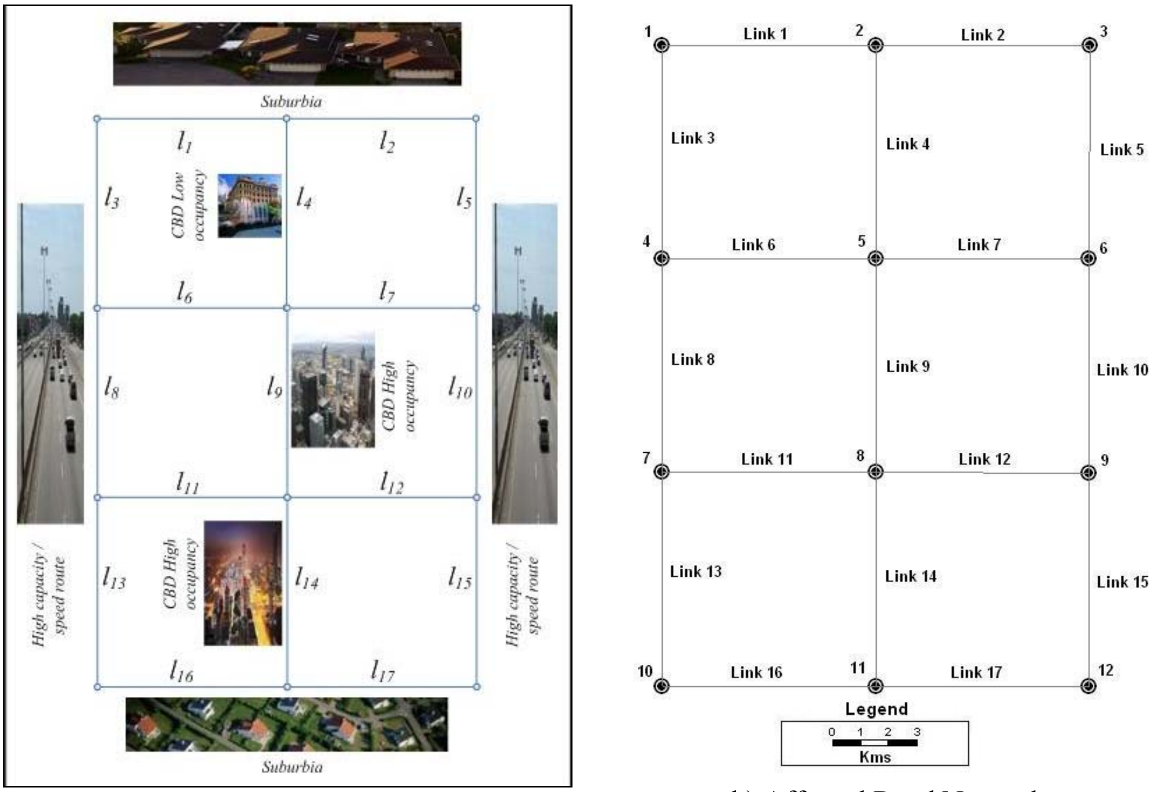
- **Panel #1:** Presents general resource allocation recommendations. Also, button "*Generate Resource Deployment Recommendation*" opens the results from the optimisation routine window (bottom right corner), which contains results from the proposed logistics model identifying the three optimum deployment strategies;
- **Panel #2:** Resource deployment strategy to be filled in by the case study participant;
- **Panel #3:** Access to both available maps and GIS Data;
- **Panel #4:** Available road network data previously the event (e.g. flows, capacity, repair cost, lengths, unitary logistics and transportation costs); and
- **Panel #5:** Presents maps selected from the Panel #3.

6.2 DRRT Case Study

This section presents the case study conducted to assess the DRRT System as proposed in the last chapter. We initially specify how the case studies were set up as well as the emergency scenario simulation and the data collection procedure. A Data Analysis Method is presented considering the data collected during the simulations so a final assessment about DRRT's efficiency and applicability in real contexts could be drawn.

6.2.1 Case Study Set Up and Scenario Specification

An emergency scenario was developed using a number of previous experiences reported by Gohil (2005), Newlands (2006), Ferreira *et al.* (2010a, 2010b, 2010c) and the ResOrgs (2008). Thus, an earthquake occurring at 3.00am with the epicentre location within 10 km from the Central Business District (CBD) of a hypothetical region (Figure 6-5a) was specified. The event created a 75 kilometre surface rupture along the fault and the ground was displaced horizontally by up to 5 metres and vertically by up to 1 metre. It produced damage on links 6, 8, 9 and 14 (Figure 6-5b) as well as coordination among numerous responding organisations (e.g. Civil Defence, City Council, Contractors, Consultants, National Transportation Agency). The transport problem was further simulated by specifying damage information (lost capacity, resource need, delayed vehicles), traffic flows, road capacity, repair costs and available resources/locations.



a) Affected Region

b) Affected Road Network

Figure 6-5: Emergency Scenario Affected Region.

In the specific context of the transport problem, case study participants were required to deploy available resources to damaged links in a given road network. To do so, they had to define the number of resources to be allocated to each link as well as their respective origins. Eight resource units are available at three locations (depots located at nodes 1, 9 and 10) and total damage demand 40 resource units/day, i.e. at least 5 response days would be required to clear all damage

The scenario was embedded in the DRRT case study application so it could be dynamically simulated. As previously highlighted, it links upcoming events with previous decisions made by the case study participant. The experiment was also set up to emulate DRRT's functions (e.g. graphical interfaces, map presentations, data display, recommendation prompts) in order to provide the case study participant with a feeling on how the system would be when operational.

Similarly to a real disaster, the case study application presents the end-user with emergency information and allows him/her to perform a vast number of decisions. Each one of the 25 decisions listed in Table 6-1 is associated with a number of marks for individual response phases (refer to Appendix C). It ultimately represents the quality or accuracy of the decision-making process adopted by the participant. The final performance was estimated according to the number of marks accumulated during the simulation and time taken to make decisions. Marks were assigned to each decision (outstanding: 100 marks, good: 75 marks, acceptable: 50 marks, poor: 25 marks and wrong: 0 marks) according to an optimum course of actions defined for the proposed emergency scenario. Note that the optimum course of actions is qualitatively defined by the developer as the gaming technique allows the controller to do so accordingly to proposed rules for the given scenario under simulation.

Table 6-1: Response Actions.

ID	Response Action
1	Contact Civil Defence
2	Contact contractors
3	Contact consultants
4	Contact City Councils
5	Enquire Civil Defence
6	Enquire contractors
7	Enquire consultants
8	Enquire City Councils
9	Contact NZTA local office
10	Contact NZTA regional office
11	Contact NZTA national office
12	Contact NZ Police
13	Contact National Emergency Controller
14	Mobilize physical resources
15	Mobilize human resources
16	Deploy human resources (management)
17	Deploy physical resources (damage repair)
18	Check available communication technologies
19	Define information procedures
20	Set up Emergency Operations Centre (EOC)
21	Define organisation's response objectives
22	Define organisation's response priorities
23	Define emergency needs
24	Projection of future instances
25	No action

Additionally, the emergency scenario simulates a physical resource allocation task. Thus, the case study participant was required to assign resources from given origins (depots) to damage locations in order to respond to the event by fixing a given road network. Performance was estimated comparing costs (logistics and response delay costs) associated with individual deployment strategies adopted by the participant and the optimum ones identified in Appendix E.

Finally, the participant was required to play the role of the emergency manager coordinator. He/she was in charge of liaising with involved organisations as well as be responsible in deploying resources following the priorities defined by the National Emergency Controller.

6.2.2 Data Collection Procedure

A simple data collection procedure was implemented taking advantage of opportunities from information technologies and the case study application developed. Most of data to be collected is automatically performed by the DRRT case study application. In this context, decisions taken, time elapsed, number of resources deployed to individual road links and their origins, initial and final survey answers and any additional information logged by the participant are recorded in text formats for further analyses. The exercise controller is required to observe the simulation progress in order to capture general additional information to be used in the analysis process.

6.2.3 Data Analysis Method

A four stage Data Analysis Method (Figure 6-6) was designed making use of the DRRT case study application and its available tools. Eleven participants took part on the DRRT case study simulations. At the end of each simulation, data was recorded in text formats in order to allow compatibility with any data processing tool selected by the analyst. The unique data set representing the whole simulation process was then filtered so further procedural decision-making and resource deployment analyses could be performed.

Two data sets (i.e. procedural decision-making and resource deployment) were used to conduct the data analyses. Initially, individual decision-making performances are compared according to the level of decision support used. In this respect, decision-making effort (time taken) and accuracy (points) are estimated for procedural decision-making actions, e.g. "Contact Councils", "Check communication availability". Additionally, response costs (logistics and response delay) are estimated for individual deployment strategies and compared against optimum resource deployment identified using the resource allocation optimisation routine proposed in the chapter 5 (refer to Appendix E for optimum results).

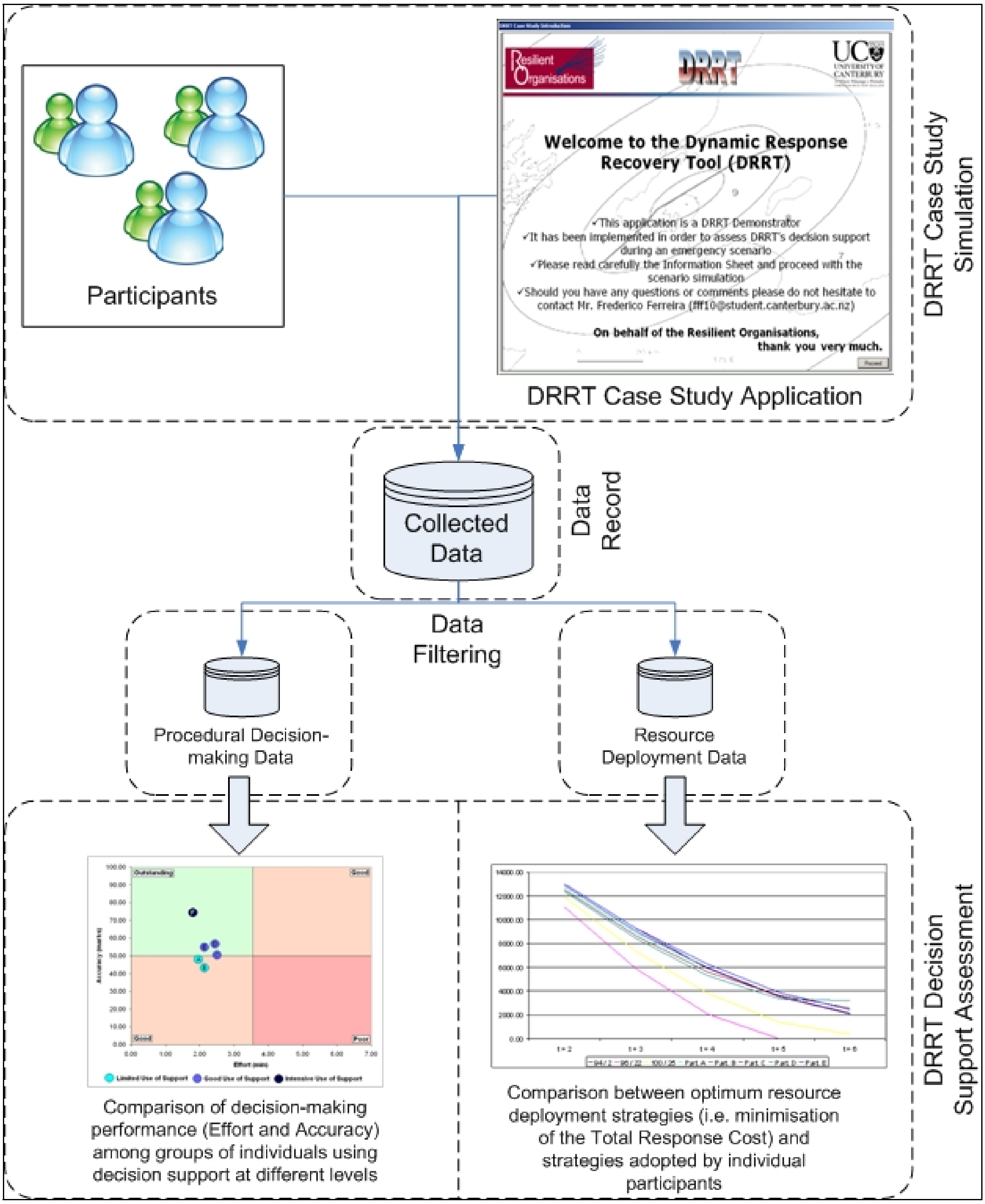


Figure 6-6: DRRT Simulation Data Analysis Method.

6.2.4 Case Study Simulations

Simulations were conducted over a two-month period in Christchurch and Wellington (New Zealand). Case study participants were selected from industry, academia and college students from the University of Canterbury (UoC) in order to represent as many facets as possible of emergency practices taught and adopted in New Zealand.

The case studies were performed at both individual and group settings according to research opportunities developed during the case study period. On one hand, individual simulations were carried out with representatives from the industry (e.g. consultants and contractors) as well as professionals directly or indirectly involved in emergency management at their respective organisations. On the other hand, a group simulation took place with a class of 16 students from the Hazards Management course hosted by the Geology Department at the University of Canterbury.

Although one-to-one and group settings were used to run the case studies, they did not vary much in essence. Both settings used the same IT application and simulation conditions (e.g. scenario specification, opportunity to interact with the exercise controller). Finally, all case study simulations were vital in collecting complete data sets to assess the DRRT in accordance with proposed steps shown in Figure 6-6.

One-to-one simulations took place at participants' venue so no burden was added to volunteers. The researcher was responsible to schedule a time and visit the organisations to run the simulations. The case study application was uploaded onto a notebook so the simulation and data collection were fully automated.

The case studies were performed following a simple process. The researcher initially briefed the experiment by presenting the research aim and describing the application (i.e. main decision-making window, resources deployment window and etc). Additional questions were then answered by the researcher in order to clarify how the application should be operationalised so possible technical difficulties could be reduced during the simulation process. The application was started as soon as the participant agreed with the Information Sheet, which further specified the experiment and ensured privacy requirements according to the University of Canterbury's Ethic Committee standards.

The emergency scenario formally started after a quick initial survey is filled by the participant. One-to-one simulations lasted in average 45 minutes (including the 24 procedural decision-making and the deployment of physical resources) and were finalised with a survey about the application. An unstructured interview/discussion time was encouraged by the researcher at the end of each simulation so further data and general impressions from the experiment could be gathered.

Individual simulations comprised eleven people from four different organisations. Participants' and organisations' names were suppressed in Table 6-2 due to privacy and ethic requirements of the University of Canterbury.

Table 6-2: Individual DRRT Simulations.

Participant	Professional Experience [4]	Position or Team	Organisation
A	High	Facilities manager	Tertiary institution
B	High	Asset management	Transportation consultancy
C	High	Asset management	Transportation consultancy
D	High	Asset management	Transportation consultancy
E	High	Asset management	Transportation consultancy
F	Low / Medium	Lecturer	Tertiary institution
G	High	Civil Defence manager	Local council
H	Low	Maintenance	National wide contractor
I	Medium	Contractual	National wide contractor
J	High	Asset manager	National wide contractor
K	Low	Asset management	National wide contractor

Although some participants did not hold formal positions in emergency management, emergency response behaviour and decision-making indicated comprehensive knowledge on response procedures. In this light, participants were either regularly involved in the management of real

[4] Professional Experience: Low – 0 to 5 years; Medium – 5 to 10 years; High – 10+ years

emergencies and/or were immersed in cutting edge emergency management research and exercises nationally and internationally.

Overall, participants demonstrated considerable interest in the proposed DRRT. Most simulations finally culminated in discussions on how to improve the proposed system as well as how such initiatives could fulfil inter and intra-organisational training needs. The DRRT's concept and case study application were well received by participants and feedbacks/comments were constructive.

Two data sets were compiled after running one-to-one simulations. The first data set, known as procedural decision-making, acquired managerial decisions taken by case study participants during the simulation. It recorded action taken, time, accuracy (marks) and outcomes for all decisions made according to the list presented in Table 6-1.

General decision-making patterns were identified in the way that participants responded the scenario. Table 6-3 shows that participants focused on communication (i.e. contacting and enquiring external organisations) in order to ensure that information sharing protocols were up to acceptable standards so information loss could be reduced. The definition of response objectives along with resource mobilisation and deployment were consistently performed to support a well structured response according to data shown in Table 6-3. This behaviour indicated the participants' good reasoning because information was firstly gathered before resources were allocated according to established objectives. Such decision-making pattern points out to strategic approaches as decisions were seldom modified due to new events. Communication checks and EOC set up were lowly ranked, not due to low priority, but exclusively due to the fact that it only needs to be performed once while responding an event. Finally, the projection of future needs appears in the last position as the scenario does not require taking into consideration the recovery process. It only exercises three initial response days after a major event. Additional columns with the frequency (minimum, average and maximum) that each decision category was performed per participant have been included in Table 6-3 so differences in decision processes can be observed.

All raw data collected during the one-to-one simulations are available in Appendix D for further reference.

Table 6-3: Procedural Decision-making Patterns: One-to-one Simulations.

Decision-making Activity	Times Performed	Minimum	Average	Maximum
Contact (Civil Defence, Consultants etc)	89	4	8	15
Enquire (Civil Defence, Consultants etc)	39	0	4	9
Define (Response Objectives)	36	0	3	7
Deploy (Physical and Human Resources)	34	0	3	6
Mobilise (Physical and Human Resources)	33	0	3	6
Check / Set up (Communications, EOC)	21	0	2	4
Project (Future Needs)	11	0	1	2

Participants were finally required to allocate resources in a damaged road network according to rough priorities defined for the scenario (e.g. evacuation, search and rescue and business continuity). Thus, participants had to specify both number of resources to each damage destination and their origins. Similarly to Procedural Decision-making, raw data collected for this simulation task can be found in the Appendix D.

Specifically during resource deployment, some participants reported difficulties to fully comprehend the situation and/or claimed to struggle to perform such task due to lack of specific information. An interesting observation refers to a comprehensive situation awareness and familiarity for contractors to deal with resource allocation activities. Nevertheless whenever struggles were noticed, the exercise controller directly engaged with participants in order to ensure that all necessary data to support decisions were noticed. The controller also provided any additional information to help the participant without biasing the process. Hence, this engagement only aimed at maintaining data collection up to standards that would allow further analyses.

In spite of struggles faced by participants, the resource deployment activity was informative. Data collected allowed us to understand the reasoning applied when allocating resources. It was observed that participants initially assessed the availability of alternative routes and considered response priorities (e.g. business continuity, evacuation and search and rescue) before making final decisions. Tangible consequences from the disaster, such as delayed vehicles, lost road capacity and so on, were also considered when assessing possible decision-making courses. Ultimately, logistics costs were only evaluated in regards to travel time. When enquired about deployment costs, participants stated unanimously that economic costs associated with emergencies are much more related to further damage and loss of life rather than to the actual cost of resource mobilisation and usage. Nonetheless, none assessment routines or methods were pointed out by the eleven participants. This fact indicates a high reliance on general knowledge and past experiences, which can be inaccurate or unavailable at times.

Like the one-to-one simulations, the group experience allowed us to collect Procedural Decision-making and Resource Deployment data. The group simulation occurred at the University of Canterbury's Emergency Operation Centre (EOC) and involved 16 students. Two teams of five and one team of six students represented the national transport agency (Team C), a contractor (Team A) and a consultant (Team B), respectively. Each team was placed in a different room at the EOC and could only contact each other through an available landline extension. The simulation set up intended to represent the current state highway management framework adopted by the New Zealand Transport Agency.

The students attended a quick brief about the simulation as for the individual participants. They were further encouraged to define a team structure to facilitate the decision-making. The EOC environment helped the students to set up the team, i.e. define roles such as communication, logistics, operations, controller.

The experience was productive in presenting the students with common issues to be managed during an emergency. Time pressure was slightly introduced towards the end of the simulation due to time restrictions. It consequently introduced a common issue to be dealt with when managing real emergencies. On one side of the spectrum, communication difficulties, data collection and organisation, information loss etc were some of the problems identified when observing the teams during the simulations. On the other side, DRRT facilitated decisions and information management as reported by students during a hot debrief at the end of the simulation.

A specific assessment of the DRRT is performed in the next section. Both individual and group simulations complimentarily support to scrutinize data collected and facts observed during the case study period. Ultimately, the DRRT System is investigated in its potentials to facilitate decision-making during real emergency events within the roading organisations context.

6.3 Results from the DRRT Case Studies

There were two specific goals when analysing DRRT case studies: i) to understand the support offered by the DRRT for procedural decision-making and ii) to identify how resource allocation activities can be facilitated by using the proposed resource allocation optimisation routine.

Aiming at the analysis of decision support offered by the DRRT, we initially proceeded with the study of decision-making effort and accuracy. This first assessment measure refers to decision-making planning (effort) and performance (accuracy) for procedural decisions (e.g. communication check, EOC set up, organisational enquiries). It is assumed that outstanding decision-making is achieved when planning time (defined as elapsed time between consecutive decision-making actions) is reduced and effective or accurate response is accomplished. Accuracy is associated with marks assigned to each possible decision (Table 6-1) at individual times accordingly to the scenario simulated (refer to Appendix C for further details). Figure 6-7 presents average results for all participants according to different levels of support information considered (i.e. limited, good and intensive) and the three groups of students. The use of recommendations (decision support) was assessed during individual simulations by observing participants' actions and complimentarily enquiring them at the end of the simulation. It aimed at assessing how useful and often recommendations were considered before making decisions. Although the same data was also collected for the group setting, it was not considered as students had differing perceptions about the DRRT. Thus, the estimation of a single indicator for a whole group was considered unrealistic due to different roles simulated (e.g. team leader, communication manager, logistics manager), personal expertise/experiences and expectations.

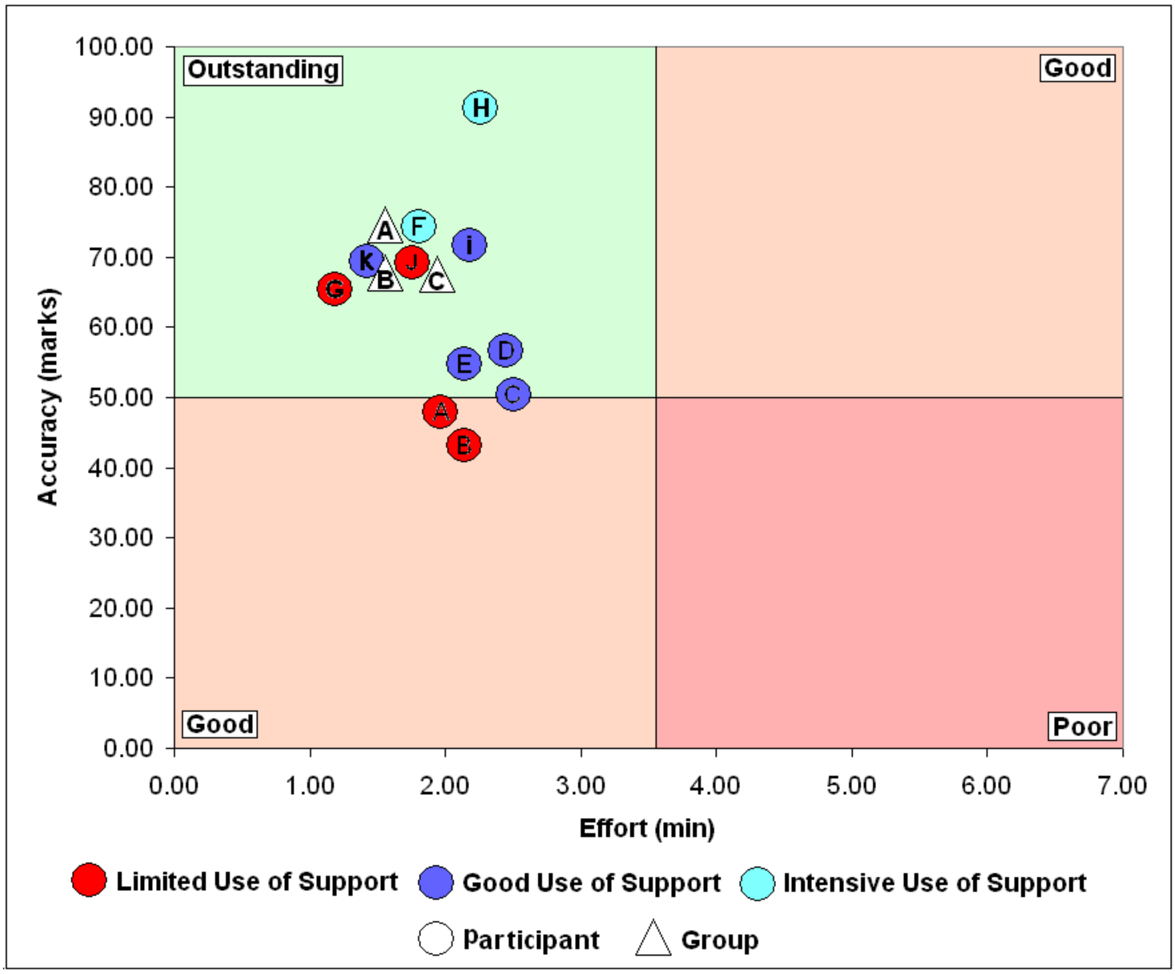


Figure 6-7: Average Decision-making Effort (Planning Time) and Accuracy (Performance).

Individual decision-making performance increases considerably when DRRT's support information is intensively considered as shown in Figure 6-7. For instance, participant F who is enthusiastic about hazards and emergency management research, responded to the scenario with high regard for DRRT's recommendations and made intensive use of available tools. Also, the participant H has achieved the highest decision-making accuracy regardless being an inexperienced professional (at the time of the research he was hired as a junior road maintenance engineer). When enquired about his decisions, he stated that it was based on injects, priorities and recommendations given by the DRRT. He finally mentioned that DRRT's recommendations have considerably helped to trigger alternative courses of response (i.e. it did not automate his decision-making process) by providing expert knowledge on disaster response.

Triggering and supporting decision-making are seen as major characteristics of any expert system. Thus, findings highlighted in the last paragraph confirm the expert system nature of the DRRT. Note that the recommendations provided by the DRRT throughout the simulation did not necessarily represent the best decision to be made (i.e. decisions with a 100 marks), but were instead designed to alert the end-user about issues that might have been underestimated. In this context, it can be argued that maps, GIS data, recommendation prompts and expected outcomes were fundamental for participants F and H in achieving high decision-making performances. Finally, data collected for the abovementioned participants show that only approximately 10 out of 48 decisions made achieved 50 marks or less indicating their consistent decision-making processes throughout the simulation.

On the contrary, Participant B showed some scepticism about decision support for big scale events, such as the one simulated (an earthquake). His poor performance can be associated with lack of consideration of DRRT's support or lack of interest in the case study experiment. Nonetheless, he declared at the final survey that the DRRT can be useful for localised events so we can discard the lack of interest in the experiment. It is suspected that his behaviour originates from his comprehensive practical experience and strong familiarity with emergency procedures, which culminated in over confidence making him unaware of many considerations to be taken before making the decisions. Therefore, a poor consideration of DRRT's available tools is the most likely reason associated with his limited decision-making performance.

An interesting fact is highlighted by the observed performances of participants G and J. In spite of a limited use of decision support, both participants had accurate decision-making. Their high performance can be associated with experiences, consistent emergency training and management of real events. For instance, participant G has already acted as the emergency manager for the EOC and has been local civil defence staff for many years. Likewise, participant J was already involved in emergency exercises and practiced the substantial role of communication manager (information collection and liaising with external organisations) for a major road network in the country.

The abovementioned highlight interesting findings in the context of the DRRT assessment. For participant F and H, it is important to emphasise that the accuracy of results provided by the decision support system needs to be always interpreted. End-users should not follow the systems' recommendations immediately, but need to check its reasonableness. Moreover, different clusters of organisations manage diverse complexities. Hence, DRRT's outputs can facilitate decision-making in different contexts. For instance, the restoration of an electricity network can be predicted with the precision of hours or days while rebuilding major infrastructures can be accurately estimated within months or years time frames. Thus, end-users have to assess the level of accuracy required to support his/her decisions (Greco, 2010). As highlighted in the literature review and reinforced by Greco (2010), decision support tools aim at accurately providing recommendations (i.e. outcomes with correct or true values), but end-users are still required to determine the applicability of computer-generated solutions.

Information presentation and end-user demands are to be better comprehended. Although being sceptical, Participant B partially supported the use of decision support systems for localised emergency events. This indicates that clear information presentation and simple system routines could potentially increase the acceptance and performance of decision support tools. Finally, the findings highlighted through participants G and J experiments indicate that regardless support or not some decision makers will have good performances due to personal experiences and emergency management knowledge. In such cases, the value of decision support systems needs to be previously assessed in face of its development cost as possible benefits.

Additionally, teams confirmed better performances than individuals, with the exception of Participants F and H. In general, this fact indicates the intended synergy between Participant F and the DRRT. It can be argued that the system was capable to free the participant from performing time consuming activities, such as information log, data search, visual representations and so on

(Pomykalski *et al.*, 1999). It is also understood that additional human expertise was provided to Participant F through system's recommendations and prompts.

Figure 6-7 illustrates that the DRRT did not contribute for quicker decision-making (i.e. effort). It indicates that when under pressure staff (regardless of experience) were able to systematically apply their knowledge to make decisions within limited time frames. It is additionally shown in Table 6-4 that good and intensive users of support had higher planning time averages than limited ones. This fact raises concerns as greater the planning time, shorter the execution time and vice-versa. Nonetheless, good users had considerable better decision accuracy than limited users and a single instance for the two intensive users (one decision took 21 minutes) increased the average planning time for this group of participants. In spite to the both instances, higher accuracy suppresses the increased planning time as considerable better performances were achieved by those using the DRRT more consistently. For instance, participant F achieved almost double of marks than participants B and participant H had an incredible high accuracy in his decisions.

Table 6-4: Decision-making Performance: Effort.

	Decision Support Usage		
	Limited	**Good**	**Intensive**
	Minutes	Minutes	Minutes
Average Planning Time	1.76	2.15	2.06
Maximum Planning Time	10.00	14.00	21.00
Minimum Planning Time	1.00	1.00	1.00
Standard Deviation (Planning Time)	1.48	1.92	3.01

In this backdrop, the relationship between planning and execution times needs to be properly considered as long planning can imply in insufficient execution time frames. Thus, inappropriate planning activities can potentially jeopardise response by reducing efficiency or ultimately making impossible for plans to be executed. Hence, caution in presenting support information is recommended. Increased planning times for participants C, D and E can be possibly related with information overload or inaccuracies, which created difficulties for decision-making, instead of facilitating it. Nevertheless, this fact cannot be interpreted as a DRRT limitation because increased decision accuracy (i.e. approximately 15 marks) is much more representative than the additional planning time of 0.39 minutes.

Figure 6-8 presents the decision-making accuracy box plot diagram for participants and groups. Observe that decision performance between limited and good DRRT users are very similar (same 25 percentile, median and 75 percentile). However, the average accuracy is slightly higher (5 marks) for participants using the DRRT at good levels when compared to limited users. A great shift in performance was perceived with participants using the DRRT intensively. Only 25% of decisions had accuracy bellow 75 marks (i.e. 25 percentile is equal 75 marks).

In general, participants consistently employing the DRRT achieved better decision-making quality than those disregarding the DRRT. Figure 6-7 and Figure 6-8 illustrate such finding. This fact points out to the support offered by the DRRT in managing emergencies and highlights the potential efficiency and suitability of the system to support extreme events decision-making. Hence, the DRRT system, as proposed in this research, shows promising future opportunities to evolve into an operational management system.

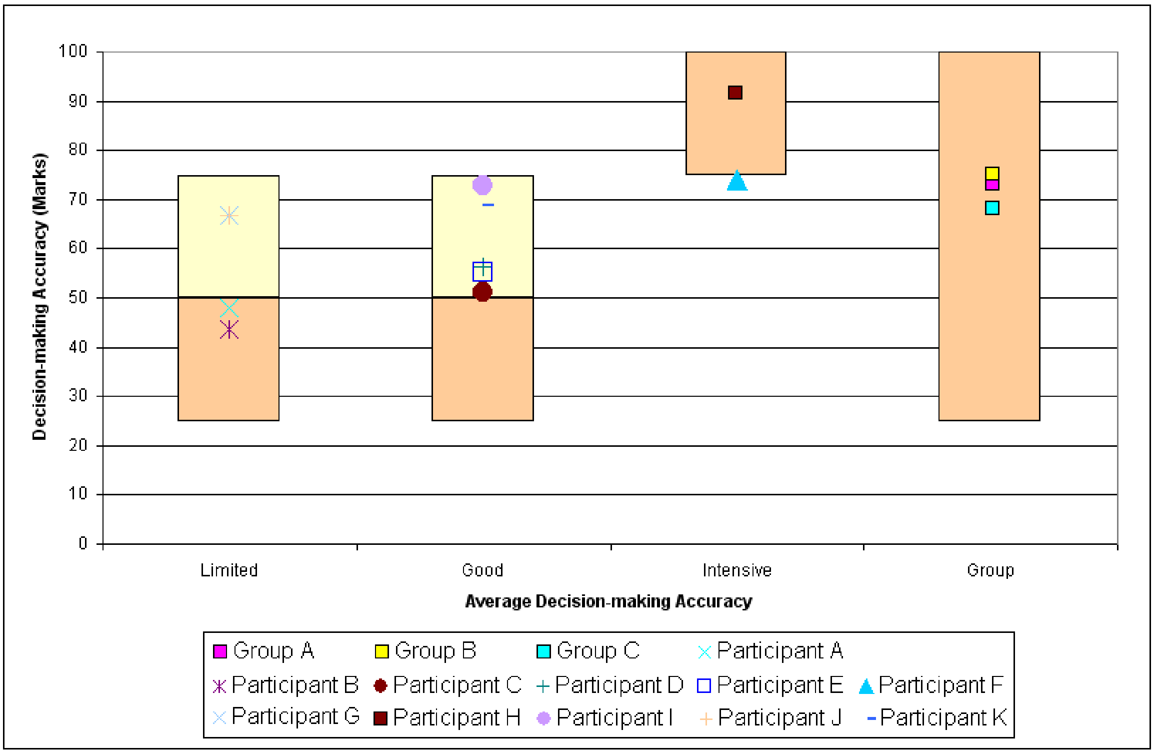


Figure 6-8: Decision-making Performance Box Plot and Individual Results: Accuracy.

On the specific context of resource allocation, data acquired was valuable and informative to assess the logistics model proposed in chapter 5. The constrained situation created by the seventeen link network was appropriate to collect data for further analyses. It has shown to be comprehensive and technically sound for the intended case study set up. Participants had to consistently assess the situation comprising resource availability and needs, road network layout, damage experienced, traffic flows, lost capacity, conflicting priorities and etc before deploying resources. It ultimately simulated common challenges faced by roading organisations when managing emergencies affecting a network.

During the simulation, both quantitative and qualitative data were collected. Quantitative information was recorded by the DRRT application and represented the number of resources deployed to each damaged link as well as their origins. Qualitative notes were taken by the researcher in order to reflect additional reasoning considered by the participant.

Acquired data were used to process results and analyse participants' decision-making as well as verify the realism of the logistics model. In this context, data collected was processed to estimate two cost components: i) Total Response Costs (*TRC*) and ii) Total Logistics Costs (*TLC*). Costs were respectively calculated according to Equations 6-1 and 6-4 and summed for all times t.

Figure 6-9 illustrates *TRC* for strategies adopted by participants A to F and three optimum ones identified by the resource allocation model proposed (Appendix E). Results for group simulations were suppressed because of technical difficulties. The exercise controller was not able to clarify misunderstandings (commonly observed during individual simulations) so collected data did not have the minimum quality needed for analyses. Additionally, participant G did not perform the resource allocation task and participants H to K had a very particular behaviour when allocating resources. Both cases are further explored in detail.

Participants A to F reduced response costs similarly to the least optimum strategy (Optimum A). The results indicate comprehensive situation awareness and knowledge, because they needed to consider a complex set of information before allocating the resources. Although decisions could be better made (optimum strategies B or C), we enforce that differences between the three optimum strategies are virtually insignificant. In this backdrop, participants achieved good results in regard to resource allocation, which represent their abilities to deal with complex information and conflicting priorities.

In a general sense, the logistics model captured and represented the reasoning applied by decision makers when deploying resources. For instance, both model and participants' behaviours seem to target similar damage when allocating resources in the context of the proposed scenario. The logistics model prioritises links 8, 9 and 14. Observe higher proportion of resources deployed to such links as shown in Table 6-5. A similar pattern is also observed among participants A, B, E and F as illustrated in Table 6-5. This approach is correct because link 6 has a very low priority due to its high road capacity and low traffic volume, which finally incurs in small number of vehicles delayed and low costs.

Table 6-5: Resource Allocation.

	Link 6	**Link 8**	**Link 9**	**Link 14**
Optimum A	0	4	1	3
Optimum B	1	0	3	4
Optimum C	0	2	3	3
Participant A	2	2	2	2
Participant B	0	4	2	2
Participant C	4	0	1	3
Participant D	4	0	0	4
Participant E	0	4	2	2
Participant F	1	3	2	2

As previously mentioned, participant G did not perform the resource allocation task. When enquired why, he stated that this decision was missed, because he assumed that maps with damage would automatically pop up throughout the simulation. Thus, he thought that physical damage was not still assessed so resources should not be deployed. It indicates a good reasoning in spite the missed decision.

Additionally, participants H to K presented a very distinct deployment strategy. Decisions to allocate physical resources were commonly made up to three times during the simulation. This fact indicates a particular response behaviour from contractors, who are in charge to conduct repairs during emergencies. Hence, the great importance focused in such activity, which is progressively made throughout the emergency. Finally, contractor's staff showed a very comprehensive awareness about physical resources and were fully knowledgeable about gear specification (diggers, trucks, excavators), production rates, costs and traffic management needs (e.g. detour, traffic flows).

At a first glance, logistics costs seemed to be properly minimised, with the exception of participants B and C. Figure 6-10 indicates similar logistics costs between the optimum strategies and participants A, D, E and F. Nonetheless, it is concluded that participants B and C only had higher costs, because resources were deployed twice (or relocated). Such decision pattern seems to be correct, particularly after observing contractor's staff. The sole use of logistics costs to assess decision-making is therefore not recommended.

In this backdrop, it is conclude that decision makers do not aim at reducing logistics costs exclusively, but focus on travel time instead. When enquired about the driving factors behind resource deployment, case study participants answered that resources should be relocated as many times as needed as long as travel times did not compromise the execution of necessary work.

Therefore, resource allocation activities have shown to be a flexible, but strategic response activity. Complementary exercises and real events observations and game simulations support this finding, which indicates the contribution of the logistic cost to estimate travel time and its relation to repair execution.

In summary, the case studies conducted indicated that the use of DRRT (e.g. recommended actions, maps, resource deployment optimization recommendation) can indeed facilitate decision-making by increasing performance (accuracy) of decision-making processes. As shown in Figure 6-7, participants who considered decision support information more frequently had better performance than the ones disregarding it. Many participants highlighted that the proposed system can substantially help emergency managers. On one side of the spectrum, mapping technologies can help organisations to better share information, communication prompts can avoid information loss, response actions record can ease staff shifts change and etc. On the other side of the spectrum, the estimation of future instances (i.e. “Expected Results” tool) still needs considerable refinement to properly represent reality. Case studies also validated the resource deployment routine proposed in chapter 5. Data and facts collected during the resource deployment stage highlight the reasonableness behind the formulation of the response and logistics costs.

Finally, note that the intrinsic conceptual nature of the Resource Allocation Optimisation Routine proposed in the last chapter and applied for the scenario defined in Figure 6-5 might not be applicable for real cases with dozen of damaged sites and hundreds of links. Therefore, the outputs from the model application shall be analysed by emergency management experts before making decisions as the reliability of the information generated might be questionable for real and complex scenarios. It is also highlighted the need to conduct specific studies to properly define the proposed parameters in the model (i.e. travel cost, loading/unloading cost and vehicle delay cost) in order to ensure adequacy of outcomes for specific cases under consideration. For such matter, local culture and economic indicators are recommended to be considered so sensitive analyses can be performed in order to find the best set of coefficients.

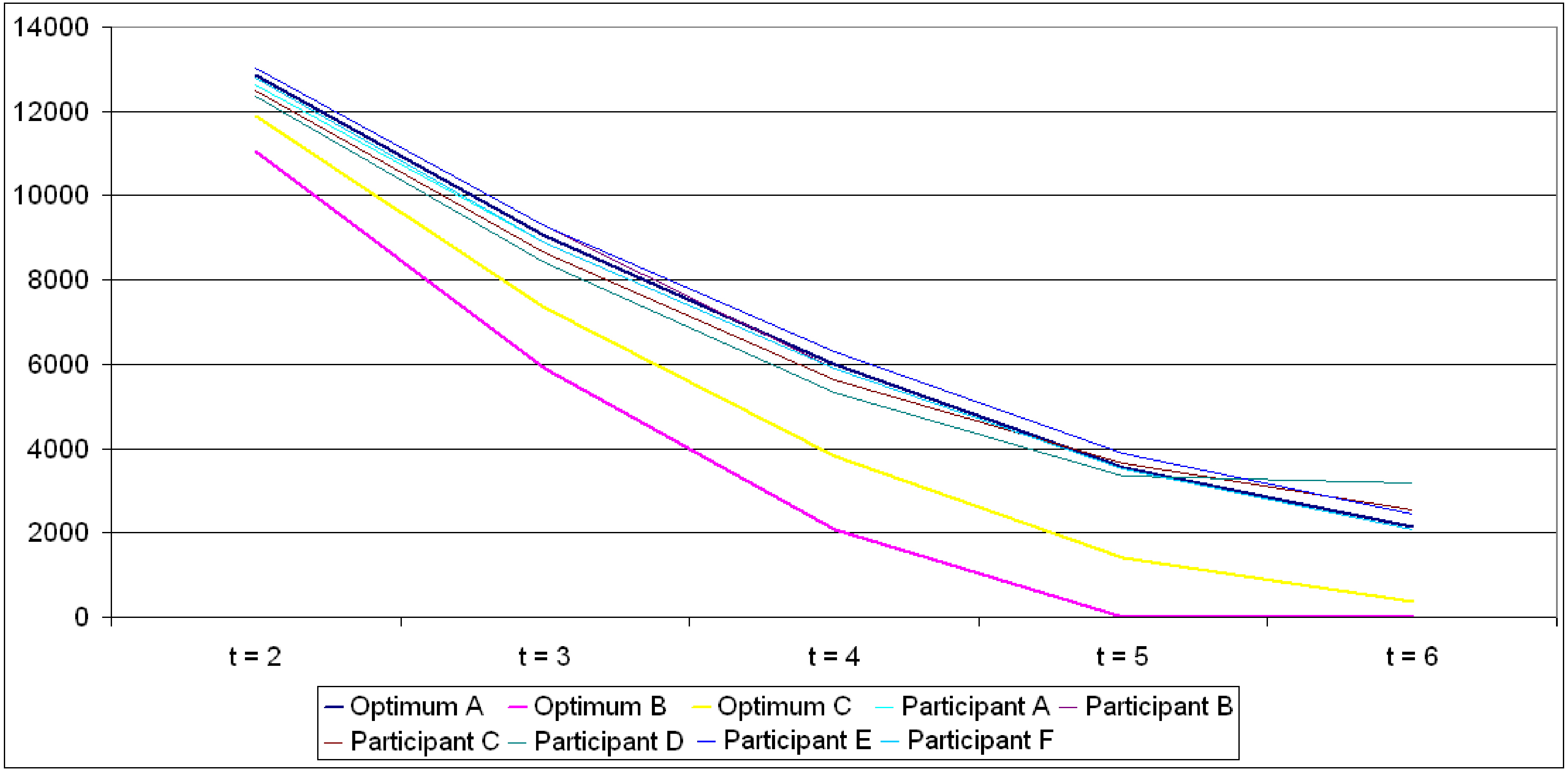


Figure 6-9: Total Response Costs – *TRC*.

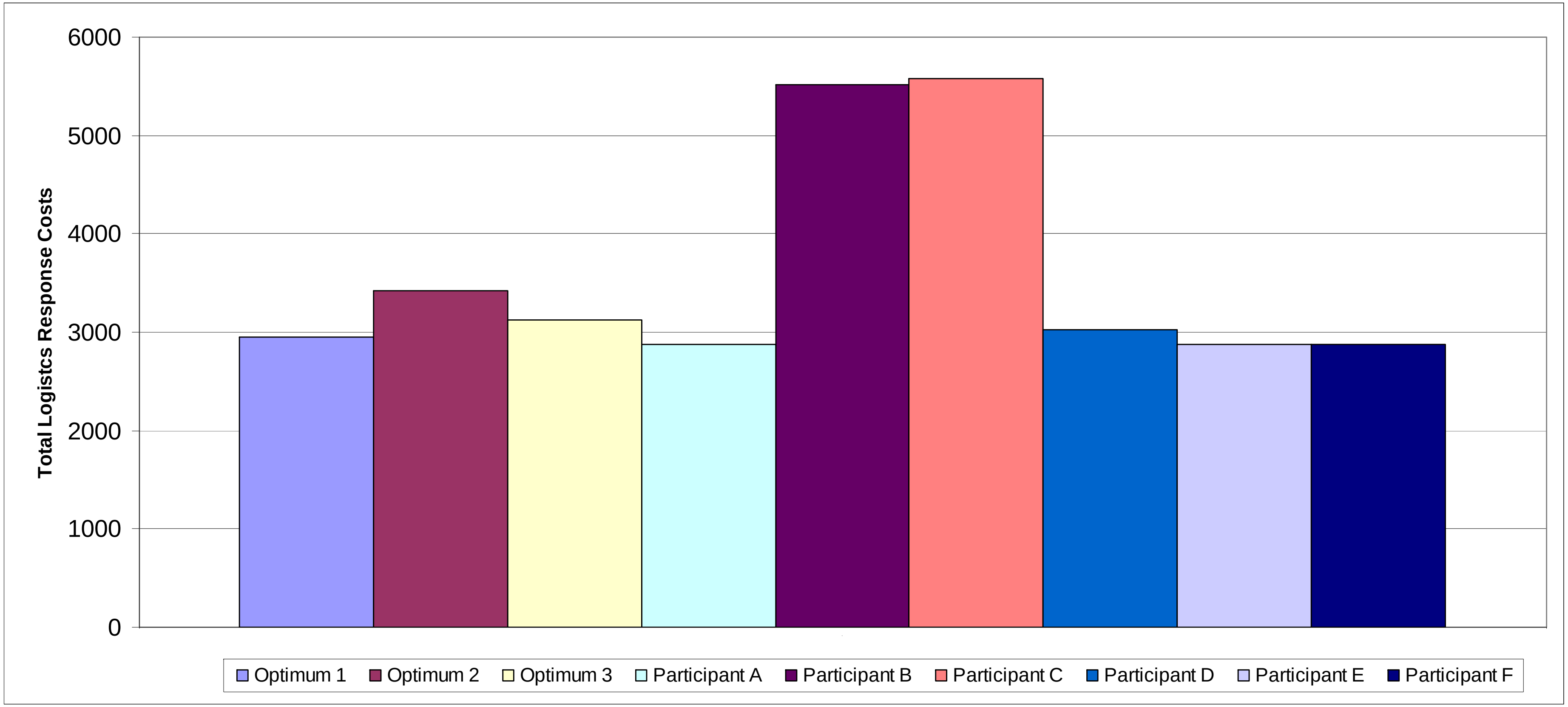


Figure 6-10: Total Logistics Costs - *TLC*.

7 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the findings of this research. It also confirms the hypothesis that the DRRT can enhance decision-making during emergency events. Additionally, we perform a critical analysis of both contributions and limitations of the DRRT to finally recommend future research endeavours.

The chapter is divided in four sections. After this brief introduction, research findings are summarised. In the sequence, the DRRT is evaluated along with its contributions towards decision support during emergency events. The third section is dedicated to the analysis of DRRT's limitations and the final section lists some recommendations and suggestions for future research.

7.1 Research Findings

This research achieved a number of findings at both emergency management and transportation fields. Overall, the findings were elucidative in the context of emergency events decision-making and finally helped to develop new and hopefully useful knowledge underpinned by the DRRT system. The following list enumerates the most representative research findings from the observation of real and simulated events and game simulations:

- Emergency management is a highly dynamic process, in which information sharing plays a vital role. In this context, organisations practice procedures and develop awareness in order to avoid information loss and inconsistency in multi-agency responses;
- The complexity of emergency decision-making has its genesis on the need to integrate the four decision-making domains (i.e. physical, information, cognitive and social);
- Good situation awareness and knowledge were identified for the physical, information and social decision-making domains. For instance, good understanding on machinery and infrastructures, comprehensive communication procedures and organisational arrangements

are well set up, respectively. Nonetheless, the cognitive domain is still unclear as reasoning on decision-making processes were seldom specified by game participants;

- Emergency scenario simulations can meet data needs for numerous research approaches, because real events are scarce and data collection procedures are hard to be implemented in the immediate aftermath of events;
- Decision-making processes adopted by game participants indicated the use of Naturalistic Decision-making models. Thus, outcomes associated with individual decisions are cognitively estimated according to similar instances experienced in the past;
- When facing non-previously experienced situations, decision makers call upon improvisation skills to make decisions. Such an approach is also described by the Naturalistic Decision-making model;
- Emergency response is clearly segmented into two time frames (e.g. short and long terms). Short term objectives aim at immediate needs such as evacuation and support to life treating circumstances, whereas long term ones target recovering normality in terms of restoring socio-economic activities. These time frames are commonly referred as emergency response and recovery, respectively;
- Emergency response and resource deployment are usually performed under strategic paradigms. Resources are seldom deployed to single or few locations as decision makers aim at attending different priorities at similar time frames;
- Physical resources are allocated in the road network in order to meet the most urgent needs according to resource availability and damage levels. This represents a cognitive processes in which the decision-maker weights priorities to finally make decisions on resource allocation;
- Common emergency response procedures were followed by game participants. In this context, at initial stages response aimed to facilitate search and rescue and then to ensure basic needs, such as water, power, medical treatment and so on;

- DRRT's functionalities support decision-makers to act in a structured and logical manner. The procedural recommendations guide the decision makers through steps of the emergency response that despite their simplicity require full and timely implementation. Procedural recommendations triggered additional decision-making reasoning for participants taking into considerations the recommendations. Ultimately, the DRRT supported decision-makers to achieve accurate decisions in the scenario simulated;
- The resource allocation model and information generated made decision makers aware of optimum deployment strategies considering a set of information, such as traffic flows, road capacity, experienced damage, response priorities and etc. Likewise procedural recommendations, this set of information supported better decisions in terms of resource allocation;
- The DRRT tool comprehensively represented emergency management knowledge as the two less experienced participants achieved the highest performances. Additionally, those were the participants fully considering the system as well as the less sceptical individuals about the idea of decision support during emergencies;
- Many participants using the system at good or intensive levels achieved similar performances to groups A, B and C. Regardless specific assessments of participants' experiences, this fact indicates that the DRRT was able to emulate human expertise through its recommendations and resource deployment information as individuals had similar or better decision accuracy than groups;
- The DRRT highlighted an existing relationship between planning and execution activities. The case studies showed that planning is a vital activity when managing emergencies, but it should not compromise execution by allowing limited time to implement response strategies; and
- The conceptualisation and assessment of the DRRT indicated at practical levels that decision makers can be freed of time demanding activities (e.g. information collection and organisation). It also supported additional reasoning when decision makers had the

tendency to be paralysed or inefficient in his/her decisions due to situation been over demanding.

7.2 Evaluation on the Contribution of the DRRT

The series of case studies presented in chapter 6 indicated that the DRRT positively contributed in facilitating decision-making during extreme events. It was observed that decision-making performance is directly proportional to how often DRRT's tools and recommendations were considered when responding to the scenario. Case study participants F and H demonstrate such an axiom, given that they were intensive users of DRRT's recommendations and had the best decision-making performances among all participants.

Conceptually wise, the DRRT represented emergency management knowledge developed in this research. Knowledge representation is considered the main technical difference between DSS/ES and ordinary information technology systems. In this context, knowledge developed through the observation of real and simulated events and game simulations were considered to propose the DRRT. For instance, communication and information sharing issues identified when observing exercises were targeted by offering an integrated technology platform containing maps, information log, injects description, decision-making summary and etc.

The naturalistic decision-making model adopted in emergencies (identified in the game simulations) was incorporated in the DRRT by general recommendations, which triggered alternative decision-making reasoning for some participants. Additionally, the DRRT platform along with the proposed logistics model were capable to process network data (e.g. traffic flows, road capacity, experienced damage) and present end-users with comprehensive information on optimum resource allocation strategies. Such strategies facilitated resource allocation decisions by considering conflicting priorities, resources limitations, response planning and etc.

Specific results indicated that the DRRT facilitated decision-making and confirmed the hypothesis that decision support tools facilitate decision-making during emergency events. Case study participants using the system at intensive levels achieved in average decisions 28% more accurate than good users and 31% better than limited users. Furthermore, 75% of decisions made by intensive users were assessed outstanding or good (75 marks or more), while others participants had only 25% of decisions with such an accuracy. Finally, numerous participants stated that the tools available and information generated can indeed support decisions in real situations.

7.3 DRRT Limitations

The main drawback identified in the DRRT was its limiting capacity in encouraging people to use the tools available. As shown in the case studies in chapter 6, only two out of eleven participants used the system in its full capacity. Although many more used the system at good levels, it was frequently observed lack of full consideration of available tools. Ultimately, the DRRT could not eliminate the common scepticism associated with decision support tools for complex multi-disciplinary problems, such as emergency management.

We also identified specific limitations as listed bellow. We reinforce, though, that they are consequences of recent developments in the emergency management field and not a direct related to the research method applied.

- **Information technology:** better information presentation and graphical user interfaces can potentially encourage end-users are to use decision support systems due to simple and efficient operation;
- **Knowledge representation:** in spite to the great deal of knowledge developed for roading organisations, the DRRT was limited in considering emergency management in a holistic manner. Issues such as welfare, legislation, policies and etc were not considered when developing the DRRT; and
- **Physical resources:** limited understanding was developed and incorporated into the DRRT about physical resources. This mostly refers to knowledge already available with field staff, i.e. contractors.

7.4 Recommendations for Future Research

Despite the considerable knowledge development and outcomes generated with this research, some recommendations for future research are listed as follows:

- **Emergency training package:** is strongly recommended to evolve the DRRT framework application into a comprehensive training package to reduce simulation costs and improve results. The initial test ran with a class of students pointed out for alternative ways to simulate multi-agency exercises. In this respect, a dynamic platform in which responses from individual organisations affect information feed and scenario development to external organisations can be practiced, increasing the realism of simulations;
- **Virtual training environment:** complimentarily to the previous recommendation, we suggest the development of a complete scenario set using virtual reality paradigms and human interface technologies in order to simulate a real emergency setting to test human reactions to decision support;
- **Increase realism of scenario simulation:** it is expected that future endeavours will consider real scenarios instead of hypothetical simulations. The decision to use a hypothetical city representation has been made due to resource and time limitations associated with this particular research. However, it has been found a great deal of knowledge about possible disasters scenarios for numerous cities, e.g. Wellington – New Zealand, Vancouver – Canada. In this context, participants will not be detracted from the simulation as it will have real meaning as well as complexities experienced in real life;
- **Field integration and overlap reduction:** concepts and knowledge developed throughout this research indicate the need to explore the opportunities to integrate expertise from different fields of knowledge. The DRRT development and test shown that "*pluggings*" from a particular fields (e.g. geology, political sciences) can be embedded into the application in order to practice alternative emergency scenarios; therefore, reduce redundant research and development effort;

- **Multi-disciplinary integration for better emergency management practices:** strong integration among the social, physical, management, law and engineering fields is encouraged in order to overcome shortcomings from each area of knowledge. The recent "discovery" of emergency management research and the increasing number of disasters incurs the need to quickly evolve concepts and practices to reduce loss of life and economic disruptions;
- **Integration with well established practices in the academia and industry:** the use of consecrated techniques such as logistics and supply chain management can support the description of the logistics of disasters or humanitarian logistics concept as part of the integration between emergency management and supply chain management;
- **Resource allocation mathematical modelling:** further development on mathematical formulations of the resource optimisation routine needs to be conducted. Network reliability, logistics and optimisation techniques should be explored in order to develop a complete resource allocation model;
- **Human knowledge representation:** there should be further studies that could incorporate other cognitive techniques to represent human knowledge. Such a research effort may lead to high accuracy levels in terms of recommendations and improved design DSS/ES to assist decision-making; and
- **Integration with artificial intelligence:** a comprehensive approach of expert system and artificial intelligence should be endeavoured in order to represent human knowledge. Therefore, dynamic knowledge could be added into systems' knowledge base in order to simulate human expertise similarly to a human being.

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GLOSSARY

1) Textual abbreviations

AELG	= Auckland Egineering Lifelines
AHP	= Analitical Hierarchy Process
AI	= Artificial Intelligence
BI	= Business Inteligence
BoP	= Bay of Plenty
CBD	= Central Business District
CCRP	= Defence Command and Control Research Program
CD	= Civil Defence
CDEM	= Civil Defence and Emergency Management
CELG	= Canterbury Engineering Lifelines Group
CIMS	= Co-ordinated Incident Management System
CLIPS	= C Language Integrated Production System
DGIS	= Dynamic Geographic Information System
DGM	= Data Gathering Module
DLM	= Data Log Module
DM	= Decision Making
DoC	= Department of Conservation
DRRT	= Dynamic Response Recovery Tool
DRRT-GUI	= Dynamic Response Recovery Tool Graphical User Interface
DSS	= Decision Support Systems
DST	= Decision Support Tool
DLCs	= Decision and Learning Cycles
DSSR	= Decision Support Systems Resources
EDS	= Eruption Detection System
EMA	= Emergency Management Australia
EMYCIN	= Empty MYCIN
EOC	= Emergency Operations Centre
ES	= Expert Systems
FEMA	= Federal Emergency Management Agency
GEOC	= Group Emergency Operations Centre
GIS	= Geographic Information Systems
GUI	= Graphical User Interface
GWRC	= Greater Wellington Regional Council
HLS	= Humanitarian Logistics Software
HPP	= Heuristic Programming Project
ICS	= Incident Control System

IDE	= Integrated Development Environment
IE	= Inference Engine
IFRCRCS	= The International Federation of Red Cross and Red Cross Crescent Societies
IT	= Information Technology
KB	= Knowledge Base
MCDEM	= Ministry of Civil Defence and Emergency Management
MES	= Management Expert Systems
MIS	= Management Information Systems
MIT	= Massachusetts Institute of Technology
MoU	= Memorandum of Understanding
MSF	= Microsoft Solution Framework
NASA	= National Aeronautics and Space Administration
NIMS	= National Incident Management Systems
NLG	= Northland Lifelines Group
NZ	= New Zealand
NZFD	= New Zealand Fire Department
NZTA	= New Zealand Transport Agency
OD	= Origin and Destination
OLAP	= On line Analytical Processing
OODA	= Observe-Orient-Decide-Act
OS	= Operational Systems
PDSS	= Planning and Decision Support Systems
PSC	= Public Safety Canda
PSS	= Planning Support Systems
NTR	= Network Terminal Reliability
RCAs	= Roading Controlling Authorities
ResOrgs	= Resilient Organisations Research Programme
R&D	= Research and Development
RT	= Radio Transmitter
SAGAT	= Situation Awareness Global Assessment Technique
SDST	= Spatial Decision Support Tool
SHO	= State Highway Organisations
UoC	= University of Canterbury
UPS	= United Parcel Service
VB	= Visual Basic

APPENDIX A – HUMAN ETHICS COMMITTEE APPROVAL

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Human Ethics Committee

Secretary

Tel: +64 3 364 2241, Fax: +64 3 364 2856, Email: human-ethics@canterbury.ac.nz

Ref: HEC 2008/142

9 December 2008

Mr Frederico Ferrerira
Department of Civil and Natural Resources Engineering
UNIVERSITY OF CANTERBURY

Dear Frederico

The Human Ethics Committee advises that your research proposal "Dynamic response recovery tool for emergency response within State Highway Organisations in New Zealand" has been considered and approved.

Best wishes for your project.

Yours sincerely

pp Dr Michael Grimshaw
Chair, Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. *www.canterbury.ac.nz*

APPENDIX B – GAME SIMULATION DATA BASE

Importance Matrix:

Participant A

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	9	8	9	9	6	6	9
Protect Private Property	1/9	1	1/5	1	1	1/6	1/2	1/5
Support Lifelines	1/8	5	1	4	4	1	1	2
Protect Economy	1/9	1	1/4	1	5	1	1/5	1/2
Protect Environment	1/9	1	1/4	1/5	1	1/5	1/9	1/3
Enable Support from other Areas	1/6	6	1	1	5	1	3	9
Repair Key Infrastructure	1/6	2	1	5	9	1/3	1	5
Facilitate Accessibility Between Communities	1/9	5	1/2	2	3	1/9	1/5	1

Participant B

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	7	3	5	7	7	3	3
Protect Private Property	1/7	1	1/5	1/3	1	3	3	3
Support Lifelines	1/3	5	1	5	5	1	1	1
Protect Economy	1/5	3	1/5	1	1/3	1/3	1/3	1/3
Protect Environment	1/7	1	1/5	3	1	1/3	1/3	1
Enable Support from other Areas	1/7	1/3	1	3	3	1	1	1
Repair Key Infrastructure	1/3	1/3	1	3	3	1	1	3
Facilitate Accessibility Between Communities	1/3	1/3	1	3	1	1	1/3	1

Participant C

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	3	1	3	3	1	1	3
Protect Private Property	1/3	1	1/7	1/2	1/3	1/5	1/5	1/2
Support Lifelines	1	7	1	3	3	1	2	2
Protect Economy	1/3	2	1/3	1	1	1/3	1/3	1/2
Protect Environment	1/3	3	1/3	1	1	1/5	1/3	1
Enable Support from other Areas	1	5	1	3	5	1	1	1
Repair Key Infrastructure	1	5	1/2	3	3	1	1	1
Facilitate Accessibility Between Communities	1/3	2	1/2	2	1	1	1	1

Participant D

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	9	1/9	9	8	1/3	1/9	1/7
Protect Private Property	1/9	1	9	1/2	1/2	1/5	1/7	1/7
Support Lifelines	9	1/9	1	9	5	1	3	1
Protect Economy	1/9	2	1/9	1	1/3	1/5	1	1/7
Protect Environment	1/8	2	1/5	3	1	1/7	1/3	1/9
Enable Support from other Areas	3	5	1	5	7	1	9	1
Repair Key Infrastructure	9	7	1/3	1	3	1/9	1	1/7
Facilitate Accessibility Between Communities	7	7	1	7	9	1	7	1

Participant E

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	6	8	2	4	8	8	7
Protect Private Property	1/6	1	1/6	1/4	1/4	1/8	1/8	1/7
Support Lifelines	1/8	6	1	1/5	1/6	1/8	1/7	1/6
Protect Economy	1/2	4	5	1	1/4	1/8	1/7	1/7
Protect Environment	1/4	4	6	4	1	1/8	1/8	1/7
Enable Support from other Areas	1/8	8	8 1/2	8	8	1	1/2	1/4
Repair Key Infrastructure	1/8	8	7 1/2	7	8	2	1	1/6
Facilitate Accessibility Between Communities	1/7	7	6	7	7	4	6	1

Participant F

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	5	2	6	5	4	2	5
Protect Private Property	1/5	1	2	4	4	2	5	4
Support Lifelines	1/2	1/2	1	4	3	1	1	2
Protect Economy	1/6	1/4	1/4	1	2	1/2	1/3	1/2
Protect Environment	1/5	1/4	1/3	1/2	1	1/2	1/2	1
Enable Support from other Areas	1/4	1/2	1	2	2	1	1/2	1
Repair Key Infrastructure	1/2	1/5	1	3	2	2	1	2
Facilitate Accessibility Between Communities	1/5	1/4	1/2	2	1	1	1/2	1

Participant G

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	8	2	8	8	4	3	3
Protect Private Property	1/8	1	1/5	5	3	1/4	1/2	3
Support Lifelines	1/2	5	1	6	8	2	1/2	3
Protect Economy	1/8	1/5	1/6	1	1	1/2	1/4	1/2
Protect Environment	1/8	1/3	1/8	1	1	1/3	1/4	1/2
Enable Support from other Areas	1/4	4	1/2	2	3	1	1/2	1
Repair Key Infrastructure	1/3	2	2	4	4	2	1	3
Facilitate Accessibility Between Communities	1/3	1/3	1/3	2	2	1	1/3	1

Participant H

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	9	1	4	3	1/3	2	5
Protect Private Property	1/9	1	1/2	3	1	1/3	2	1/5
Support Lifelines	1	2	1	3	2	1/3	1	5
Protect Economy	1/4	1/3	1/3	1	1	1/5	1/2	1/2
Protect Environment	1/3	1	1/2	1	1	1/3	1/2	1/2
Enable Support from other Areas	3	3	3	5	3	1	2	3
Repair Key Infrastructure	1/2	1/2	1	2	2	1/2	1	1
Facilitate Accessibility Between Communities	1/5	5	1/5	2	2	1/3	1	1

Participant I

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	9	1	9	7	5	9	9
Protect Private Property	1/9	1	1/9	1	1/3	1/9	1/5	1/3
Support Lifelines	1	9	1	9	7	3	9	9
Protect Economy	1/9	1	1/9	1	1/5	1/9	1/5	1/7
Protect Environment	1/7	3	1/7	5	1	1/9	1/7	1
Enable Support from other Areas	1/5	9	1/3	9	9	1	1	9
Repair Key Infrastructure	1/9	5	1/9	5	7	1	1	2
Facilitate Accessibility Between Communities	1/9	3	1/9	7	1	1/9	1/2	1

Participant J

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	5	1	5	3	1	1	1
Protect Private Property	1/5	1	1/5	1/5	1/3	1/7	1/5	1/5
Support Lifelines	1	5	1	1/5	1/3	1	1	1
Protect Economy	1/5	5	5	1	1/3	1/5	1/5	1/5
Protect Environment	1/3	3	3	3	1	1/5	1/5	1/5
Enable Support from other Areas	1	7	1	5	5	1	1	1
Repair Key Infrastructure	1	5	1	5	5	1	1	1
Facilitate Accessibility Between Communities	1	5	1	5	5	1	1	1

Participant K

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	7	5	7	7	3	7	7
Protect Private Property	1/7	1	1/7	1/7	1/9	1/9	1/9	1/7
Support Lifelines	1/5	7	1	7	3	3	7	7
Protect Economy	1/7	7	1/7	1	1/7	1/7	1/9	1/7
Protect Environment	1/7	9	1/3	7	1	3	3	3
Enable Support from other Areas	1/3	9	1/3	7	1/3	1	1/7	1
Repair Key Infrastructure	1/7	9	1/7	9	1/3	7	1	5
Facilitate Accessibility Between Communities	1/7	7	1/7	7	1/3	1	1/5	1

Participant L

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	9	3	9	7	3	3	7
Protect Private Property	1/9	1	1/9	1/3	1/7	1/9	1/9	1/5
Support Lifelines	1/3	9	1	9	9	5	7	5
Protect Economy	1/9	3	1/9	1	1/4	1/9	1/7	1/7
Protect Environment	1/7	7	1/9	4	1	5	1/5	1/7
Enable Support from other Areas	1/3	9	1/5	9	1/5	1	1/5	1
Repair Key Infrastructure	1/3	9	1/7	7	5	5	1	3
Facilitate Accessibility Between Communities	1/7	5	1/5	7	7	1	1/3	1

Resource Deployment:

Participant A

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	6	6	4	10	0	10	0	10	0
2	0	0	0	0	0	0	1	1	3
3	0	0	4	4	3	7	0	7	0
4	0	0	0	0	0	0	0	0	0
5	0	0	2	2	0	2	0	2	4
6	0	0	0	0	0	0	2	2	3
7	2	2	0	2	0	2	4	6	0
8	0	0	0	0	3	3	0	3	1
9	0	0	0	0	2	2	4	6	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	2	2	1
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	2	2	0	2	5	7	0	7	0
Airport	0	0	0	0	0	0	0	0	1
TOTAL	**10**	**-**	**10**	**-**	**13**	**-**	**13**	**-**	**13**
							End of Sim		**59**

Participant B

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	5	5	5	10	0	10	0	10	0
2	4	4	0	4	0	4	0	4	0
3	0	0	4	4	3	7	0	7	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	5	5	0
7	0	0	0	0	0	0	5	5	1
8	0	0	0	0	3	3	3	6	0
9	0	0	0	0	0	0	0	0	4
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	1	1	1	2	5	7	0	7	8
Airport	0	0	0	0	2	2	0	2	0
TOTAL	**10**	**-**	**10**	**-**	**13**	**-**	**13**	**-**	**13**
							End of Sim		**59**

Participant C

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	2	2	0	2	0	2	0	2	0
2	0	0	0	0	0	0	0	0	0
3	0	0	7	7	0	7	0	7	0
4	2	2	1	3	0	3	0	3	0
5	0	0	0	0	0	0	4	4	2
6	0	0	0	0	5	5	0	5	0
7	2	2	0	2	0	2	0	2	0
8	0	0	0	0	4	4	0	4	0
9	0	0	0	0	0	0	6	6	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	8
14	4	4	2	6	1	7	0	7	0
Airport	0	0	0	0	0	0	0	0	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**10**
							End of Sim		**50**

Participant D

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	0	0	0	0	0	0	0	0	0
2	1	1	1	2	0	2	2	4	0
3	0	0	2	2	0	2	4	6	1
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	5
6	0	0	4	4	1	5	0	5	0
7	6	6	0	6	0	6	0	6	0
8	1	1	1	2	1	3	1	4	0
9	0	0	0	0	1	1	2	3	3
10	0	0	0	0	0	0	0	0	0
11	1	1	1	2	0	2	0	2	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	1	1	1	2	5	7	1	8	1
Airport	0	0	0	0	2	2	0	2	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**10**
							End of Sim		**50**

Participant E

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	2	2	2	4	3	7	3	10	0
2	1	1	1	2	2	4	1	5	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	3	3	0	3	0	3	0
6	0	0	0	0	1	1	1	2	1
7	4	4	1	5	0	5	0	5	0
8	0	0	0	0	0	0	0	0	2
9	0	0	0	0	2	2	2	4	2
10	0	0	0	0	2	2	2	4	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	2	2	0	2	0	2	0	2	4
14	1	1	3	4	0	4	1	5	4
Airport	0	0	0	0	0	0	0	0	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**13**
							End of Sim		**53**

Participant F

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	2	2	3	5	0	5	3	8	2
2	0	0	0	0	3	3	3	6	0
3	0	0	2	2	0	2	0	2	5
4	2	2	2	4	0	4	0	4	0
5	0	0	3	3	0	3	0	3	3
6	0	0	0	0	2	2	4	6	0
7	3	3	0	3	0	3	0	3	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	3	3	0	3	5	8	0	8	0
Airport	0	0	0	0	0	0	0	0	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**10**
							End of Sim		**50**

Participant G

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	3	3	1	4	1	5	2
4	1	1	1	2	1	3	1	4	0
5	0	0	3	3	3	6	0	6	0
6	0	0	0	0	2	2	3	5	0
7	6	6	0	6	0	6	0	6	0
8	0	0	0	0	0	0	1	1	3
9	0	0	0	0	0	0	1	1	5
10	0	0	0	0	2	2	1	3	0
11	0	0	0	0	0	0	2	2	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	3	3	3	6	1	7	0	7	0
Airport	0	0	0	0	0	0	0	0	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**10**
							End of Sim		**50**

Participant H

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	2	2	2	4	2	6	4	10	0
2	0	0	0	0	0	0	1	1	3
3	0	0	2	2	2	4	3	7	0
4	0	0	0	0	0	0	0	0	0
5	0	0	1	1	5	6	0	6	0
6	0	0	0	0	0	0	2	2	3
7	4	4	3	7	0	7	0	7	0
8	0	0	0	0	0	0	0	0	4
9	0	0	0	0	0	0	0	0	2
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	1
14	4	4	2	6	1	7	0	7	0
Airport	0	0	0	0	0	0	0	0	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**13**
							End of Sim		**53**

Participant I

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	7	7	3	10	0	10	0	10	0
2	0	0	0	0	0	0	3	3	1
3	0	0	2	2	2	4	3	7	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	5
6	0	0	0	0	4	4	1	5	0
7	3	3	0	3	0	3	3	6	0
8	0	0	0	0	4	4	0	4	0
9	0	0	0	0	0	0	2	2	4
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	3
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	5	5	2	7	0	7	0
Airport	0	0	0	0	1	1	1	2	0
TOTAL	**10**	**-**	**10**	**-**	**13**	**-**	**13**	**-**	**13**
							End of Sim		**59**

Participant J

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	1	1	1	2	1	3	2	5	2
2	0	0	0	0	0	0	1	1	1
3	0	0	1	1	1	2	3	5	2
4	2	2	2	4	1	5	0	5	0
5	1	1	2	3	0	3	0	3	0
6	0	0	0	0	0	0	0	0	0
7	2	2	1	3	0	3	0	3	1
8	0	0	0	0	2	2	2	4	0
9	0	0	0	0	1	1	1	2	3
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	2	2	1	3	0	3	0	3	0
14	2	2	2	4	3	7	0	7	1
Airport	0	0	0	0	1	1	1	2	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**10**
							End of Sim		**50**

Participant K

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	0	0	3	3	0	3	7	10	0
2	2	2	0	2	0	2	0	2	2
3	2	2	2	4	0	4	0	4	3
4	0	0	1	1	0	1	0	1	0
5	0	0	1	1	0	1	0	1	5
6	3	3	0	3	0	3	0	3	2
7	3	3	2	5	1	6	0	6	0
8	0	0	0	0	0	0	3	3	1
9	0	0	0	0	1	1	0	1	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	7	7	0	7	0
Airport	0	0	1	1	1	2	0	2	0
TOTAL	**10**	**-**	**10**	**-**	**10**	**-**	**10**	**-**	**13**
							End of Sim		**53**

Participant L

	Resources Mobilized								
	1st Movement	Net Total	2nd Movement	Net Total	3rd Movement	Net Total	4th Movement	Net Total	5th Movement
1	0	0	0	0	0	0	0	0	0
2	2	2	0	2	0	2	0	2	0
3	0	0	0	0	0	0	0	0	7
4	1	1	1	2	0	2	0	2	0
5	0	0	0	0	0	0	1	1	3
6	2	2	1	3	1	4	1	5	0
7	1	1	3	4	2	6	0	6	0
8	1	1	1	2	2	4	0	4	0
9	1	1	1	2	4	6	0	6	0
10	0	0	1	1	0	1	0	1	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	7	7	0
Airport	0	0	1	1	1	2	0	2	0
TOTAL	**8**	**-**	**9**	**-**	**10**	**-**	**9**	**-**	**10**
							End of Sim		**46**

APPENDIX C – DRRT CASE STUDY APPLICATION SCENARIO SPECIFICATION

Decision Instance	Time	Injects	Response Targets	ID	Response Activity	Accuracy (Points)	Expected Outcome	Outcome Information / Inject
-	3.00 am	-	Earthquake happens	-	Nil	Nil	-	-
1st	6.00am (1st day)	Set 1	Response begins. Start operations in emergency mode. Sort organisational procedures for response. Define organisation's mission in response efforts. Define organisation's priorities in response efforts. Identify possible communication technologies to be used.	1	Contact Civil Defence	50	Establish information loop with Civil Defence / Data sharing and disseminating	Civil Defence not reached: Failed communication / No response
				2	Contact contractors	50	Establish information loop with contractors / Data sharing and disseminating	Contractors reached: RTs operational and limited cell phone coverage.
				3	Contact consultants	50	Establish information loop with consultants / Data sharing and disseminating	Consultants reached: Cell phone limited, dedicated landline channel and no e mail communication
				4	Contact City Councils	50	Establish information loop with the City Council / Data sharing and disseminating	City Council reached: Cell phone limited, dedicated landline channel and no e mail communication
				5	Enquire Civil Defence	25	Collect information about number of affected people, deaths and needs / Data collection	Failed communication / No response
				6	Enquire contractors	25	Collect information about road damage and available resources / Data collection	Unspecific damage information about Mt. Victoria and The Terrace tunnels
				7	Enquire consultants	25	Reinforce technical scheme of response and provide technical advice / Data collection	No specific information, but damage throughout the state highway network has been already reported by numerous sources
				8	Enquire City Councils	25	Collect information about local community needs / Data collection	Supporting local community rescue efforts
				9	Contact NZTA local office	50	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Liaising with regional office to start emergency operations
				10	Contact NZTA regional office	50	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Endeavouring to collect information on road damage and external organisations' needs
				11	Contact NZTA national office	50	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Strategic information priorities released by fax communication early on
				12	Contact NZ Police	50	Establish information loop with Police and collect on site information / Data sharing and disseminating	No much specific information currently. Information about abandoned vehicle, panic and public disobedience
				13	Contact National Emergency Controller	50	Acquire strategic information at National level / Data sharing and disseminating	Defining National Response Planning
				14	Mobilize physical resources	0	Identify and organise available physical resources for immediate deployments / Fuel dependency and availability / Local, regional and national resources inventory	Nil
				15	Mobilize human resources	75	Identify and organise available human resources to conduct emergency management activities / Staff availability / Volunteering	Approximately 60% of your staff is available. They are heading to the EOC while 5 people is already at the EOC starting emergency operations
				16	Deploy human resources (management)	0	Damage assessment and management / Temporary traffic management / Alternative routes and detours	Nil
				17	Deploy physical resources (damage repair)	0	Repair identified and assessed damage / Increase network operationability / Driver availability / Fuel availability / Route / Resource inventory / Destination	Nil

				18	Check available communication technologies	100	Assessment of RTs, e-mail, phone, fax, satellite phone and internet communication operationability	RTs often operational, phone / fax / satellite phones usable and e-mail / internet non operational
				19	Define information procedures	50	Operationalise data collection, analysis, storing, summarising, sharing, disseminating, maintaining and updating frameworks / Communication intra-organisation, inter-organisation, with media and public information	Limited operationability of information sharing and processing frameworks
				20	Set up Emergency Operations Centre (EOC)	100	Operationalise CIMS structure (assign communication, logistics, public information, operations, emergency management roles) / Define staff shifts / Check backup power (generators) / Ensure venue safety / Arrange food needs and first aid kits	Define: CIMS structure, staff shifts, check backup power (generators), ensure venue safety, arrange food needs and first aid kits
				21	Define organisation's response objectives	100	Agree upon response objectives / Create importance matrix	Define response objectives
				22	Define organisation's response priorities	100	Establish priorities upon agreed response objectives / Fill in importance matrix	Prioritise response objectives
				23	Define emergency scenario needs	0	Forecast resource needs	Nil
				24	Projection of future instances	0	Forecast upcoming situations	Nil
2nd	9.00am (1st day)	Set 2	Establish information procedures and initiate information loop within organisation. Establish intra-organisational information loop. Acquire strategic information.	1	Contact Civil Defence	50	Establish information loop with Civil Defence / Data sharing and disseminating	Civil Defence reached: Cell phone limited, dedicated landline channel and no e mail communication
				2	Contact contractors	50	Establish information loop with contractors / Data sharing and disseminating	Contractors reached: RTs operational and limited cell phone coverage.
				3	Contact consultants	50	Establish information loop with consultants / Data sharing and disseminating	Consultants reached: Cell phone limited, dedicated landline channel and no e mail communication
				4	Contact City Councils	50	Establish information loop with the City Council / Data sharing and disseminating	City Council reached: Cell phone limited, dedicated landline channel and no e mail communication
				5	Enquire Civil Defence	25	Collect information about number of affected people, deaths and needs / Data collection	Organisation currently involved in search and rescue, wellbeing, shelter and injury treatment
				6	Enquire contractors	25	Collect information about road damage and available resources / Data collection	Unspecific damage information about tunnels and major road infrastructure
				7	Enquire consultants	25	Reinforce technical scheme of response and provide technical advice / Data collection	No specific information, but damage throughout state highway network has been already reported by numerous sources
				8	Enquire City Councils	25	Collect information about local community needs / Data collection	Supporting local community rescue efforts
				9	Contact NZTA local office	100	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
				10	Contact NZTA regional office	100	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
				11	Contact NZTA national office	100	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up

				12	Contact NZ Police	50	Establish information loop with Police and collect on site information / Data sharing and disseminating	No much specific information currently. Information about abandoned vehicle, panic and public disobedience
				13	Contact National Emergency Controller	100	Acquire strategic information at National level / Data sharing and disseminating	National Response Planning available
				14	Mobilize physical resources	25	Identify and organise available physical resources for immediate deployments / Fuel dependency and availability / Local, regional and national resources inventory	Nil
				15	Mobilize human resources	75	Identify and organise available human resources to conduct emergency management activities / Staff availability / Volunteering	Most of staff at the EOC. Staff shortages are not currently experienced
				16	Deploy human resources (management)	0	Damage assessment and management / Temporary traffic management / Alternative routes and detours	Nil
				17	Deploy physical resources (damage repair)	0	Repair identified and assessed damage / Increase network operationability / Driver availability / Fuel availability / Route / Resource inventory / Destination	Nil
				18	Check available communication technologies	75	Assessment of RTs, e-mail, phone, fax, satellite phone and internet communication operationability	RTs often operational, phone / fax / satellite phones usable and e-mail / internet non operational
				19	Define information procedures	100	Operationalise data collection, analysis, storing, summarising, sharing, disseminating, maintaining and updating frameworks / Communication intra-organisation, inter-organisation, with media and public information	Full operationability of information sharing and processing frameworks
				20	Set up Emergency Operations Centre (EOC)	75	Operationalise CIMS structure (assign communication, logistics, public information, operations, emergency management roles) / Define staff shifts / Check backup power (generators) / Ensure venue safety / Arrange food needs and first aid kits	Define: CIMS structure, staff shifts, check backup power (generators), ensure venue safety, arrange food needs and first aid kits
				21	Define organisation's response objectives	75	Agree upon response objectives / Create importance matrix	Define response objectives
				22	Define organisation's response priorities	75	Establish priorities upon agreed response objectives / Fill in importance matrix	Prioritise response objectives
				23	Define emergency scenario needs	25	Forecast resource needs	Nil
				24	Projection of future instances	0	Forecast upcoming situations	Nil
3rd	12.00pm (1st day)	Set 3	Initiate information loop among external organisations. Establish inter-organisational information loop.	1	Contact Civil Defence	100	Establish information loop with Civil Defence / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				2	Contact contractors	100	Establish information loop with contractors / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				3	Contact consultants	100	Establish information loop with consultants / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				4	Contact City Councils	100	Establish information loop with the City Council / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				5	Enquire Civil Defence	50	Collect information about number of affected people, deaths and needs / Data collection	Acquire specific information about the main regional hospital

			6	Enquire contractors	50	Collect information about road damage and available resources / Data collection	Acquire partial information about tunnels and major road infrastructure
			7	Enquire consultants	50	Reinforce technical scheme of response and provide technical advice / Data collection	Acquire information about motorway bridges
			8	Enquire City Councils	50	Collect information about local community needs / Data collection	Acquire house displacement estimation
			9	Contact NZTA local office	75	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
			10	Contact NZTA regional office	75	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
			11	Contact NZTA national office	75	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
			12	Contact NZ Police	75	Establish information loop with Police and collect on site information / Data sharing and disseminating	Abandoned vehicles at the city centre. Increasing levels of panic due to deaths and aftershocks
			13	Contact National Emergency Controller	75	Acquire strategic information at National level / Data sharing and disseminating	National Response Planning available
			14	Mobilize physical resources	25	Identify and organise available physical resources for immediate deployments / Fuel dependency and availability / Local, regional and national resources inventory	Initial contacts made towards building up resources inventory nationally and regionally. Fuel availability still unknown
			15	Mobilize human resources	75	Identify and organise available human resources to conduct emergency management activities / Staff availability / Volunteering	Most of staff at the EOC. Staff shortages are not currently experienced
			16	Deploy human resources (management)	25	Damage assessment and management / Temporary traffic management / Alternative routes and detours	Limited assessments due to site inaccessibility. Some support to police in temporary traffic management
			17	Deploy physical resources (damage repair)	25	Repair identified and assessed damage / Increase network operationability / Driver availability / Fuel availability / Route / Resource inventory / Destination	Very limited impact on initiation of repair. Waste of fuel and personnel
			18	Check available communication technologies	50	Assessment of RTs, e-mail, phone, fax, satellite phone and internet communication operationability	RTs often operational, phone / fax / satellite phones usable and e-mail / internet non operational
			19	Define information procedures	75	Operationalise data collection, analysis, storing, summarising, sharing, disseminating, maintaining and updating frameworks / Communication intra-organisation, inter-organisation, with media and public information	Full operationability of information sharing and processing frameworks
			20	Set up Emergency Operations Centre (EOC)	50	Operationalise CIMS structure (assign communication, logistics, public information, operations, emergency management roles) / Define staff shifts / Check backup power (generators) / Ensure venue safety / Arrange food needs and first aid kits	Define: CIMS structure, staff shifts, check backup power (generators), ensure venue safety, arrange food needs and first aid kits
			21	Define organisation's response objectives	50	Agree upon response objectives / Create importance matrix	Define response objectives
			22	Define organisation's response priorities	50	Establish priorities upon agreed response objectives / Fill in importance matrix	Prioritise response objectives
			23	Define emergency scenario needs	25	Forecast resource needs	Non comprehensive understanding of the "big picture"
			24	Projection of future instances	0	Forecast upcoming situations	Nil

4th	6.00am (2nd Day)	Set 4	Collect specific information on experienced damage and priorities from external organisations. Collect information. Establish inter-organisational information loop with Police to liaise operations	1	Contact Civil Defence	75	Establish information loop with Civil Defence / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				2	Contact contractors	75	Establish information loop with contractors / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				3	Contact consultants	75	Establish information loop with consultants / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				4	Contact City Councils	75	Establish information loop with the City Council / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				5	Enquire Civil Defence	100	Collect information about number of affected people, deaths and needs / Data collection	Acquire information about main regional Hospital, airport and wharf
				6	Enquire contractors	100	Collect information about road damage and available resources / Data collection	Acquire full information about tunnels and major road infrastructure
				7	Enquire consultants	100	Reinforce technical scheme of response and provide technical advice / Data collection	Acquire technical information about tunnels and major road infrastructure
				8	Enquire City Councils	100	Collect information about local community needs / Data collection	Acquire house displacement estimation and death tools
				9	Contact NZTA local office	50	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
				10	Contact NZTA regional office	50	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
				11	Contact NZTA national office	50	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
				12	Contact NZ Police	100	Establish information loop with Police and collect on site information / Data sharing and disseminating	Acquire full information about tunnels and major road infrastructure, local roads blocked by debris and abandoned cars at the CBD
				13	Contact National Emergency Controller	50	Acquire strategic information at National level / Data sharing and disseminating	National Response Planning available
				14	Mobilize physical resources	50	Identify and organise available physical resources for immediate deployments / Fuel dependency and availability / Local, regional and national resources inventory	Ongoing communications to build up resources inventory nationally and regionally. Fuel availability limited due to power outages and inaccessible CBD
				15	Mobilize human resources	50	Identify and organise available human resources to conduct emergency management activities / Staff availability / Volunteering	Most of staff at the EOC. Staff shortages are not currently experienced
				16	Deploy human resources (management)	50	Damage assessment and management / Temporary traffic management / Alternative routes and detours	Better infrastructure assessments, but not complete. Better support to police in temporary traffic management

				17	Deploy physical resources (damage repair)	50	Repair identified and assessed damage / Increase network operationability / Driver availability / Fuel availability / Route / Resource inventory / Destination	Increased impact on repair and better use of fuel and personnel. Not at optimum levels though
				18	Check available communication technologies	25	Assessment of RTs, e-mail, phone, fax, satellite phone and internet communication operationability	RTs often operational, phone / fax / satellite phones usable and e-mail / internet non operational
				19	Define information procedures	50	Operationalise data collection, analysis, storing, summarising, sharing, disseminating, maintaining and updating frameworks / Communication intra-organisation, inter-organisation, with media and public information	Full operationability of information sharing and processing frameworks
				20	Set up Emergency Operations Centre (EOC)	25	Operationalise CIMS structure (assign communication, logistics, public information, operations, emergency management roles) / Define staff shifts / Check backup power (generators) / Ensure venue safety / Arrange food needs and first aid kits	Define: CIMS structure, staff shifts, check backup power (generators), ensure venue safety, arrange food needs and first aid kits
				21	Define organisation's response objectives	25	Agree upon response objectives / Create importance matrix	Define response objectives
				22	Define organisation's response priorities	25	Establish priorities upon agreed response objectives / Fill in importance matrix	Prioritise response objectives
				23	Define emergency scenario needs	50	Forecast resource needs	Better comprehension of the emergency situation. Needs superficially surveyed
				24	Projection of future instances	25	Forecast upcoming situations	Uncomprehensive projections
5th	6.00am (3rd Day)	Set 5	Initiate formal response in terms of resources (physical and human) deployment to attend external organisation's needs. Organise and sort available physical resources. Organise and sort available human resources. Initiate human resources deployment for management efforts. Initiate physical resources deployment to clean roads, fix damage and re-establish normality.	1	Contact Civil Defence	50	Establish information loop with Civil Defence / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				2	Contact contractors	50	Establish information loop with contractors / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				3	Contact consultants	50	Establish information loop with consultants / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				4	Contact City Councils	50	Establish information loop with the City Council / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				5	Enquire Civil Defence	75	Collect information about number of affected people, deaths and needs / Data collection	Acquire information about main regional Hospital, airport and wharf
				6	Enquire contractors	75	Collect information about road damage and available resources / Data collection	Acquire full information about tunnels and major road infrastructure
				7	Enquire consultants	75	Reinforce technical scheme of response and provide technical advice / Data collection	Acquire technical information about tunnels and major road infrastructure
				8	Enquire City Councils	75	Collect information about local community needs / Data collection	Acquire house displacement estimation and death tools
				9	Contact NZTA local office	25	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up

				10	Contact NZTA regional office	25	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
				11	Contact NZTA national office	25	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
				12	Contact NZ Police	75	Establish information loop with Police and collect on site information / Data sharing and disseminating	Acquire full information about tunnels and major road infrastructure, local roads blocked by debris and abandoned cars at the CBD
				13	Contact National Emergency Controller	25	Acquire strategic information at National level / Data sharing and disseminating	National Response Planning available
				14	Mobilize physical resources	100	Identify and organise available physical resources for immediate deployments / Fuel dependency and availability / Local, regional and national resources inventory	Physical resources inventory complete
				15	Mobilize human resources	100	Identify and organise available human resources to conduct emergency management activities / Staff availability / Volunteering	Human resources availability identified
				16	Deploy human resources (management)	100	Damage assessment and management / Temporary traffic management / Alternative routes and detours	Deploy human resources to: assessments, volunteering, search & rescue, debris removal, damage repair
				17	Deploy physical resources (damage repair)	100	Repair identified and assessed damage / Increase network operationability / Driver availability / Fuel availability / Route / Resource inventory / Destination	Full impact on repair and best use of fuel and personnel
				18	Check available communication technologies	0	Assessment of RTs, e-mail, phone, fax, satellite phone and internet communication operationability	RTs often operational, phone / fax / satellite phones usable and e-mail / internet non operational
				19	Define information procedures	25	Operationalise data collection, analysis, storing, summarising, sharing, disseminating, maintaining and updating frameworks / Communication intra-organisation, inter-organisation, with media and public information	Full operationability of information sharing and processing frameworks
				20	Set up Emergency Operations Centre (EOC)	0	Operationalise CIMS structure (assign communication, logistics, public information, operations, emergency management roles) / Define staff shifts / Check backup power (generators) / Ensure venue safety / Arrange food needs and first aid kits	Define: CIMS structure, staff shifts, check backup power (generators), ensure venue safety, arrange food needs and first aid kits
				21	Define organisation's response objectives	0	Agree upon response objectives / Create importance matrix	Define response objectives
				22	Define organisation's response priorities	0	Establish priorities upon agreed response objectives / Fill in importance matrix	Prioritise response objectives
				23	Define emergency scenario needs	75	Forecast resource needs	Needs comprehensively identified
				24	Projection of future instances	50	Forecast upcoming situations	Superficial projections
6th	6.00am (4th Day)	Set 6	Project future needs and upcoming scenarios. Identify future needs in terms of human and physical resources. Identify possible upcoming events	1	Contact Civil Defence	25	Establish information loop with Civil Defence / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
				2	Contact contractors	25	Establish information loop with contractors / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost

		from the emergency. Forecast activities re-development and recovery periods.	3	Contact consultants	25	Establish information loop with consultants / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
			4	Contact City Councils	25	Establish information loop with the City Council / Data sharing and disseminating	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
			5	Enquire Civil Defence	50	Collect information about number of affected people, deaths and needs / Data collection	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
			6	Enquire contractors	50	Collect information about road damage and available resources / Data collection	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
			7	Enquire consultants	50	Reinforce technical scheme of response and provide technical advice / Data collection	Information sharing procedures and available communication technologies agreed upon. No risk of major information lost
			8	Enquire City Councils	50	Collect information about local community needs / Data collection	Acquire house displacement estimation and death tools
			9	Contact NZTA local office	0	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
			10	Contact NZTA regional office	0	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
			11	Contact NZTA national office	0	Establish and maintain information loop intra-organisation / Data storing, analysing and summarising / Data maintaining and updating	Intra-organisational information sharing procedures set up
			12	Contact NZ Police	50	Establish information loop with Police and collect on site information / Data sharing and disseminating	Acquire full information about tunnels and major road infrastructure, local roads blocked by debris and abandoned cars at the CBD
			13	Contact National Emergency Controller	0	Acquire strategic information at National level / Data sharing and disseminating	National Response Planning available
			14	Mobilize physical resources	75	Identify and organise available physical resources for immediate deployments / Fuel dependency and availability / Local, regional and national resources inventory	Physical resources inventory complete
			15	Mobilize human resources	75	Identify and organise available human resources to conduct emergency management activities / Staff availability / Volunteering	Human resources availability identified
			16	Deploy human resources (management)	75	Damage assessment and management / Temporary traffic management / Alternative routes and detours	Deploy human resources to: assessments, volunteering, search & rescue, debris removal, damage repair
			17	Deploy physical resources (damage repair)	75	Repair identified and assessed damage / Increase network operationability / Driver availability / Fuel availability / Route / Resource inventory / Destination	Full impact on repair and best use of fuel and personnel
			18	Check available communication technologies	0	Assessment of RTs, e-mail, phone, fax, satellite phone and internet communication operationability	RTs often operational, phone / fax / satellite phones usable and e-mail / internet non operational

				19 Define information procedures	0	Operationalise data collection, analysis, storing, summarising, sharing, disseminating, maintaining and updating frameworks / Communication intra-organisation, inter-organisation, with media and public information	Full operationability of information sharing and processing frameworks
				20 Set up Emergency Operations Centre (EOC)	0	Operationalise CIMS structure (assign communication, logistics, public information, operations, emergency management roles) / Define staff shifts / Check backup power (generators) / Ensure venue safety / Arrange food needs and first aid kits	Define: CIMS structure, staff shifts, check backup power (generators), ensure venue safety, arrange food needs and first aid kits
				21 Define organisation's response objectives	0	Agree upon response objectives / Create importance matrix	Define response objectives
				22 Define organisation's response priorities	0	Establish priorities upon agreed response objectives / Fill in importance matrix	Prioritise response objectives
				23 Define emergency scenario needs	100	Forecast resource needs	Needs fully surveyed
				24 Projection of future instances	100	Forecast upcoming situations	Recovery plan fully draw by projection of future needs

APPENDIX D – DRRT CASE STUDY COLLECTED DATA

Participant A Simulation Start: 2:13:00 p.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Contact NZ Police	18/02/2010 2:17:00 p.m.	4	50
2	Contact Civil Defence	18/02/2010 2:18:00 p.m.	1	50
3	Set up Emergency Operations Centre (EOC)	18/02/2010 2:18:00 p.m.	1	100
4	Mobilize human resources	18/02/2010 2:18:00 p.m.	1	75
5	Define organisation's response objectives	18/02/2010 2:21:00 p.m.	3	75
6	Define organisation's response priorities	18/02/2010 2:21:00 p.m.	1	75
7	Define emergency scenario needs	18/02/2010 2:22:00 p.m.	2	25
8	Contact contractors	18/02/2010 2:22:00 p.m.	1	50
9	Mobilize physical resources	18/02/2010 2:23:00 p.m.	2	25
10	Contact consultants	18/02/2010 2:24:00 p.m.	2	100
11	Deploy human resources (management)	18/02/2010 2:24:00 p.m.	1	25
12	Deploy physical resources (damage repair)	18/02/2010 2:24:00 p.m.	8	25
13	Projection of future instances	18/02/2010 2:32:00 p.m.	1	0
14	Contact City Councils	18/02/2010 2:35:00 p.m.	3	75
15	Contact NZTA local office	18/02/2010 2:35:00 p.m.	1	50
16	Contact National Emergency Controller	18/02/2010 2:35:00 p.m.	1	50
17	Define information procedures	18/02/2010 2:36:00 p.m.	2	50
18	No action	18/02/2010 2:37:00 p.m.	2	0
19	Contact NZTA national office	18/02/2010 2:40:00 p.m.	3	25
20	Contact NZ Police	18/02/2010 2:41:00 p.m.	2	75
21	Contact contractors	18/02/2010 2:41:00 p.m.	1	50
22	Contact consultants	18/02/2010 2:41:00 p.m.	1	50
23	Contact National Emergency Controller	18/02/2010 2:42:00 p.m.	2	0
24	Contact NZ Police	18/02/2010 2:42:00 p.m.	1	50

Participant B Simulation Start: 9:34:00 p.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Mobilize physical resources	19/02/2010 9:38:00 a.m.	4	0
2	Mobilize human resources	19/02/2010 9:38:00 a.m.	1	75
3	Deploy physical resources (damage repair)	19/02/2010 9:39:00 a.m.	2	0
4	Enquire Civil Defence	19/02/2010 9:40:00 a.m.	2	25
5	Enquire contractors	19/02/2010 9:42:00 a.m.	3	25
6	Contact NZTA local office	19/02/2010 9:42:00 a.m.	1	100
7	Set up Emergency Operations Centre (EOC)	19/02/2010 9:44:00 a.m.	3	75
8	Define organisation's response priorities	19/02/2010 9:44:00 a.m.	1	75
9	Deploy human resources (management)	19/02/2010 9:44:00 a.m.	1	0
10	Deploy physical resources (damage repair)	19/02/2010 9:46:00 a.m.	10	25
11	Enquire Civil Defence	19/02/2010 9:54:00 a.m.	1	50
12	Contact NZTA local office	19/02/2010 9:54:00 a.m.	1	75
13	Projection of future instances	19/02/2010 9:54:00 a.m.	1	0
14	Enquire contractors	19/02/2010 9:56:00 a.m.	3	50
15	Enquire Civil Defence	19/02/2010 9:57:00 a.m.	2	50
16	Deploy physical resources (damage repair)	19/02/2010 9:57:00 a.m.	1	25
17	Contact NZTA local office	19/02/2010 9:59:00 a.m.	3	75
18	Enquire contractors	19/02/2010 9:59:00 a.m.	1	50
19	Enquire contractors	19/02/2010 10:02:00 a.m.	3	75
20	Enquire Civil Defence	19/02/2010 10:02:00 a.m.	1	75
21	Contact NZTA local office	19/02/2010 10:02:00 a.m.	1	25
22	Projection of future instances	19/02/2010 10:02:00 a.m.	1	50
23	Enquire contractors	19/02/2010 10:03:00 a.m.	2	50
24	Contact NZTA local office	19/02/2010 10:03:00 a.m.	1	0

Participant C Simulation Start: 11:12:00 p.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Enquire contractors	19/02/2010 11:16:00 a.m.	4	25
2	Contact Civil Defence	19/02/2010 11:16:00 a.m.	1	50
3	Contact NZTA local office	19/02/2010 11:17:00 a.m.	2	50
4	Mobilize human resources	19/02/2010 11:17:00 a.m.	1	75
5	Check available communication technologies	19/02/2010 11:22:00 a.m.	5	75
6	Contact NZ Police	19/02/2010 11:23:00 a.m.	2	50
7	Deploy physical resources (damage repair)	19/02/2010 11:24:00 a.m.	2	0
8	Define information procedures	19/02/2010 11:24:00 a.m.	1	100
9	Define organisation's response objectives	19/02/2010 11:25:00 a.m.	2	75
10	Enquire contractors	19/02/2010 11:26:00 a.m.	2	50
11	Define organisation's response priorities	19/02/2010 11:28:00 a.m.	3	50
12	Mobilize physical resources	19/02/2010 11:29:00 a.m.	2	25
13	Define emergency scenario needs	19/02/2010 11:30:00 a.m.	2	25
14	Deploy physical resources (damage repair)	19/02/2010 11:34:00 a.m.	12	50
15	Contact NZTA regional office	19/02/2010 11:42:00 a.m.	1	50
16	Deploy human resources (management)	19/02/2010 11:43:00 a.m.	2	50
17	Projection of future instances	19/02/2010 11:43:00 a.m.	1	25
18	Mobilize human resources	19/02/2010 11:44:00 a.m.	2	50
19	Deploy human resources (management)	19/02/2010 11:45:00 a.m.	2	100
20	Deploy physical resources (damage repair)	19/02/2010 11:46:00 a.m.	2	100
21	Define organisation's response priorities	19/02/2010 11:49:00 a.m.	4	0
22	Projection of future instances	19/02/2010 11:49:00 a.m.	1	50
23	Check available communication technologies	19/02/2010 11:50:00 a.m.	2	0
24	Define emergency scenario needs	19/02/2010 11:50:00 a.m.	1	100

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Participant D Simulation Start: 12:15:00 p.m

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Contact National Emergency Controller	19/02/2010 12:20:00 p.m.	5	50
2	Set up Emergency Operations Centre (EOC)	19/02/2010 12:21:00 p.m.	2	100
3	Contact NZTA local office	19/02/2010 12:22:00 p.m.	2	50
4	Enquire Civil Defence	19/02/2010 12:23:00 p.m.	2	25
5	Contact contractors	19/02/2010 12:23:00 p.m.	1	50
6	Contact City Councils	19/02/2010 12:24:00 p.m.	2	50
7	Check available communication technologies	19/02/2010 12:25:00 p.m.	2	75
8	Contact NZ Police	19/02/2010 12:25:00 p.m.	1	50
9	Deploy human resources (management)	19/02/2010 12:26:00 p.m.	2	0
10	Deploy physical resources (damage repair)	19/02/2010 12:29:00 p.m.	14	25
11	Mobilize human resources	19/02/2010 12:40:00 p.m.	1	75
12	Define organisation's response priorities	19/02/2010 12:40:00 p.m.	1	50
13	Projection of future instances	19/02/2010 12:40:00 p.m.	1	0
14	Contact consultants	19/02/2010 12:42:00 p.m.	3	75
15	Enquire Civil Defence	19/02/2010 12:43:00 p.m.	2	100
16	Check available communication technologies	19/02/2010 12:44:00 p.m.	2	25
17	Define emergency scenario needs	19/02/2010 12:44:00 p.m.	1	50
18	Contact NZ Police	19/02/2010 12:45:00 p.m.	2	100
19	Mobilize human resources	19/02/2010 12:46:00 p.m.	2	100
20	Mobilize physical resources	19/02/2010 12:47:00 p.m.	2	100
21	Contact NZTA local office	19/02/2010 12:47:00 p.m.	1	25
22	Enquire Civil Defence	19/02/2010 12:48:00 p.m.	2	75
23	Define emergency scenario needs	19/02/2010 12:50:00 p.m.	3	100
24	Check available communication technologies	19/02/2010 12:51:00 p.m.	2	0

Participant E Simulation Start: 13:23:00 p.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Contact Civil Defence	19/02/2010 1:27:00 p.m.	4	50
2	Contact City Councils	19/02/2010 1:27:00 p.m.	1	50
3	Contact NZTA regional office	19/02/2010 1:27:00 p.m.	1	50
4	Contact contractors	19/02/2010 1:28:00 p.m.	2	50
5	Contact contractors	19/02/2010 1:32:00 p.m.	5	50
6	Contact NZTA regional office	19/02/2010 1:33:00 p.m.	2	100
7	Deploy human resources (management)	19/02/2010 1:34:00 p.m.	2	0
8	Contact NZ Police	19/02/2010 1:35:00 p.m.	2	50
9	Enquire City Councils	19/02/2010 1:36:00 p.m.	2	25
10	Contact contractors	19/02/2010 1:38:00 p.m.	3	100
11	Contact NZTA regional office	19/02/2010 1:38:00 p.m.	1	75
12	Deploy physical resources (damage repair)	19/02/2010 1:39:00 p.m.	5	25
13	Projection of future instances	19/02/2010 1:43:00 p.m.	1	0
14	Contact Civil Defence	19/02/2010 1:47:00 p.m.	4	75
15	Enquire contractors	19/02/2010 1:47:00 p.m.	1	100
16	Enquire City Councils	19/02/2010 1:47:00 p.m.	1	100
17	Contact NZTA regional office	19/02/2010 1:48:00 p.m.	2	50
18	Projection of future instances	19/02/2010 1:48:00 p.m.	1	25
19	Deploy physical resources (damage repair)	19/02/2010 1:51:00 p.m.	4	100
20	Enquire contractors	19/02/2010 1:52:00 p.m.	2	75
21	Contact NZTA regional office	19/02/2010 1:52:00 p.m.	1	25
22	Contact NZ Police	19/02/2010 1:52:00 p.m.	1	75
23	Contact NZ Police	19/02/2010 1:53:00 p.m.	2	50
24	Contact Civil Defence	19/02/2010 1:54:00 p.m.	2	25

Participant F Simulation Start: 9:14:00 a.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Set up Emergency Operations Centre (EOC)	1/03/2010 9:17:00 a.m.	3	100
2	Define organisation's response objectives	1/03/2010 9:19:00 a.m.	3	100
3	Contact contractors	1/03/2010 9:20:00 a.m.	2	50
4	Contact Civil Defence	1/03/2010 9:20:00 a.m.	1	50
5	Enquire contractors	1/03/2010 9:21:00 a.m.	2	25
6	Mobilize physical resources	1/03/2010 9:22:00 a.m.	2	25
7	Mobilize human resources	1/03/2010 9:22:00 a.m.	1	75
8	Contact NZTA regional office	1/03/2010 9:23:00 a.m.	2	100
9	Contact National Emergency Controller	1/03/2010 9:23:00 a.m.	1	50
10	Contact consultants	1/03/2010 9:24:00 a.m.	2	100
11	Contact NZTA national office	1/03/2010 9:24:00 a.m.	1	75
12	Contact City Councils	1/03/2010 9:24:00 a.m.	1	100
13	Contact consultants	1/03/2010 9:25:00 a.m.	2	100
14	Define organisation's response priorities	1/03/2010 9:26:00 a.m.	2	25
15	Define information procedures	1/03/2010 9:26:00 a.m.	1	50
16	Check available communication technologies	1/03/2010 9:26:00 a.m.	1	25
17	Enquire Civil Defence	1/03/2010 9:27:00 a.m.	2	100
18	Enquire contractors	1/03/2010 9:27:00 a.m.	1	100
19	Mobilize physical resources	1/03/2010 9:28:00 a.m.	2	100
20	Mobilize human resources	1/03/2010 9:28:00 a.m.	1	100
21	Enquire contractors	1/03/2010 9:28:00 a.m.	1	75
22	Deploy human resources (management)	1/03/2010 9:28:00 a.m.	1	100
23	Deploy human resources (management)	1/03/2010 9:29:00 a.m.	2	75
24	Deploy physical resources (damage repair)	1/03/2010 9:29:00 a.m.	6	75

Participant G Simulation Start: 8:45:00 a.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Set up Emergency Operations Centre (EOC)	22/03/2010 8:49:00 a.m.	4	100
2	Contact City Councils	22/03/2010 8:50:00 a.m.	1	50
3	Contact NZ Police	22/03/2010 8:50:00 a.m.	1	50
4	Define organisation's response objectives	22/03/2010 8:51:00 a.m.	1	100
5	Check available communication technologies	22/03/2010 8:52:00 a.m.	1	75
6	Define organisation's response priorities	22/03/2010 8:53:00 a.m.	1	75
7	Enquire contractors	22/03/2010 8:53:00 a.m.	1	25
8	Mobilize human resources	22/03/2010 8:54:00 a.m.	1	75
9	Define information procedures	22/03/2010 8:55:00 a.m.	1	100
10	Contact NZTA local office	22/03/2010 8:55:00 a.m.	1	75
11	Mobilize physical resources	22/03/2010 8:56:00 a.m.	1	25
12	Mobilize physical resources	22/03/2010 8:57:00 a.m.	1	25
13	Projection of future instances	22/03/2010 8:57:00 a.m.	1	0
14	Mobilize physical resources	22/03/2010 8:59:00 a.m.	2	50
15	Enquire contractors	22/03/2010 8:59:00 a.m.	1	100
16	Enquire contractors	22/03/2010 9:00:00 a.m.	1	100
17	Enquire City Councils	22/03/2010 9:00:00 a.m.	1	100
18	Enquire Civil Defence	22/03/2010 9:00:00 a.m.	1	100
19	Mobilize human resources	22/03/2010 9:01:00 a.m.	1	100
20	Mobilize physical resources	22/03/2010 9:01:00 a.m.	1	100
21	Mobilize physical resources	22/03/2010 9:02:00 a.m.	1	100
22	Contact NZ Police	22/03/2010 9:02:00 a.m.	1	75
23	Check available communication technologies	22/03/2010 9:02:00 a.m.	1	0
24	Define organisation's response priorities	22/03/2010 9:03:00 a.m.	1	0

Participant H Simulation Start: 9:52:00 a.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Contact National Emergency Controller	23/03/2010 9:58:00 a.m.	6	50
2	Set up Emergency Operations Centre (EOC)	23/03/2010 9:58:00 a.m.	1	100
3	Define organisation's response priorities	23/03/2010 9:59:00 a.m.	1	100
4	Check available communication technologies	23/03/2010 10:00:00 a.m.	1	100
5	Define information procedures	23/03/2010 10:02:00 a.m.	2	100
6	Contact NZTA local office	23/03/2010 10:04:00 a.m.	2	100
7	Contact NZTA regional office	23/03/2010 10:05:00 a.m.	1	100
8	Mobilize human resources	23/03/2010 10:05:00 a.m.	1	75
9	Define organisation's response priorities	23/03/2010 10:06:00 a.m.	1	75
10	Contact NZ Police	23/03/2010 10:07:00 a.m.	1	75
11	Contact consultants	23/03/2010 10:07:00 a.m.	1	100
12	Contact contractors	23/03/2010 10:08:00 a.m.	1	100
13	Contact City Councils	23/03/2010 10:09:00 a.m.	1	100
14	Enquire Civil Defence	23/03/2010 10:13:00 a.m.	4	100
15	Enquire consultants	23/03/2010 10:14:00 a.m.	1	100
16	Enquire contractors	23/03/2010 10:15:00 a.m.	1	100
17	Enquire City Councils	23/03/2010 10:15:00 a.m.	1	100
18	Contact Civil Defence	23/03/2010 10:17:00 a.m.	2	75
19	Mobilize physical resources	23/03/2010 10:19:00 a.m.	2	100
20	Deploy human resources (management)	23/03/2010 10:19:00 a.m.	1	100
21	Deploy physical resources (damage repair)	23/03/2010 10:20:00 a.m.	1	100
22	Mobilize human resources	23/03/2010 10:41:00 a.m.	21	100
23	Define emergency scenario needs	23/03/2010 10:41:00 a.m.	1	100
24	Projection of future instances	23/03/2010 10:42:00 a.m.	1	100

Participant I Simulation Start: 11:05:00 a.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Set up Emergency Operations Centre (EOC)	23/03/2010 11:09:00 a.m.	4	100
2	Check available communication technologies	23/03/2010 11:11:00 a.m.	2	100
3	Contact NZTA regional office	23/03/2010 11:14:00 a.m.	3	50
4	Define organisation's response priorities	23/03/2010 11:15:00 a.m.	1	100
5	Contact consultants	23/03/2010 11:17:00 a.m.	2	50
6	Mobilize human resources	23/03/2010 11:18:00 a.m.	1	75
7	Mobilize physical resources	23/03/2010 11:21:00 a.m.	3	25
8	Contact National Emergency Controller	23/03/2010 11:21:00 a.m.	1	100
9	Define organisation's response objectives	23/03/2010 11:22:00 a.m.	1	75
10	Contact contractors	23/03/2010 11:24:00 a.m.	2	100
11	Deploy physical resources (damage repair)	23/03/2010 11:25:00 a.m.	1	25
12	Contact contractors	23/03/2010 11:34:00 a.m.	9	100
13	Enquire City Councils	23/03/2010 11:36:00 a.m.	2	50
14	Deploy physical resources (damage repair)	23/03/2010 11:38:00 a.m.	2	50
15	Contact National Emergency Controller	23/03/2010 11:41:00 a.m.	3	50
16	Contact NZTA regional office	23/03/2010 11:42:00 a.m.	1	50
17	Enquire consultants	23/03/2010 11:43:00 a.m.	1	100
18	Deploy human resources (management)	23/03/2010 11:43:00 a.m.	1	50
19	Mobilize human resources	23/03/2010 11:46:00 a.m.	3	100
20	Deploy human resources (management)	23/03/2010 11:47:00 a.m.	1	100
21	Enquire contractors	23/03/2010 11:48:00 a.m.	1	75
22	Deploy physical resources (damage repair)	23/03/2010 11:48:00 a.m.	1	100
23	Enquire consultants	23/03/2010 11:51:00 a.m.	3	50
24	Deploy human resources (management)	23/03/2010 11:52:00 a.m.	1	75

Participant J Simulation Start: 12:08:00 p.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Set up Emergency Operations Centre (EOC)	23/03/2010 12:14:00 p.m.	6	100
2	Contact Civil Defence	23/03/2010 12:14:00 p.m.	1	50
3	Contact consultants	23/03/2010 12:16:00 p.m.	2	50
4	Contact National Emergency Controller	23/03/2010 12:17:00 p.m.	1	50
5	Define information procedures	23/03/2010 12:19:00 p.m.	2	100
6	Check available communication technologies	23/03/2010 12:20:00 p.m.	1	75
7	Contact NZTA local office	23/03/2010 12:20:00 p.m.	1	100
8	Mobilize human resources	23/03/2010 12:21:00 p.m.	1	75
9	Define organisation's response objectives	23/03/2010 12:23:00 p.m.	2	75
10	Contact Civil Defence	23/03/2010 12:25:00 p.m.	2	100
11	Define organisation's response priorities	23/03/2010 12:25:00 p.m.	1	50
12	Mobilize physical resources	23/03/2010 12:26:00 p.m.	1	25
13	Deploy human resources (management)	23/03/2010 12:27:00 p.m.	1	25
14	Contact consultants	23/03/2010 12:29:00 p.m.	2	75
15	Deploy physical resources (damage repair)	23/03/2010 12:30:00 p.m.	1	50
16	Enquire City Councils	23/03/2010 12:36:00 p.m.	6	100
17	Enquire Civil Defence	23/03/2010 12:37:00 p.m.	1	100
18	Contact NZ Police	23/03/2010 12:38:00 p.m.	1	100
19	Deploy physical resources (damage repair)	23/03/2010 12:40:00 p.m.	2	100
20	Define emergency scenario needs	23/03/2010 12:43:00 p.m.	3	75
21	Projection of future instances	23/03/2010 12:45:00 p.m.	2	50
22	Enquire consultants	23/03/2010 12:45:00 p.m.	1	75
23	Define information procedures	23/03/2010 12:47:00 p.m.	2	0
24	Contact NZTA national office	23/03/2010 12:48:00 p.m.	1	0

Participant K Simulation Start: 13:08:00 p.m.

DecisionMakingID	DecisionMaking	Time	Time Elapsed	Marks
1	Set up Emergency Operations Centre (EOC)	23/03/2010 1:14:00 p.m.	6	100
2	Contact National Emergency Controller	23/03/2010 1:15:00 p.m.	1	50
3	Define emergency scenario needs	23/03/2010 1:15:00 p.m.	1	0
4	Define organisation's response objectives	23/03/2010 1:15:00 p.m.	1	100
5	Contact NZTA national office	23/03/2010 1:17:00 p.m.	2	100
6	Check available communication technologies	23/03/2010 1:18:00 p.m.	1	75
7	Define organisation's response priorities	23/03/2010 1:18:00 p.m.	1	75
8	Contact NZ Police	23/03/2010 1:19:00 p.m.	1	50
9	Mobilize human resources	23/03/2010 1:20:00 p.m.	1	75
10	Mobilize physical resources	23/03/2010 1:20:00 p.m.	1	25
11	Contact Civil Defence	23/03/2010 1:22:00 p.m.	2	100
12	Enquire Civil Defence	23/03/2010 1:22:00 p.m.	1	50
13	Contact National Emergency Controller	23/03/2010 1:23:00 p.m.	1	75
14	Contact National Emergency Controller	23/03/2010 1:24:00 p.m.	1	50
15	Deploy human resources (management)	23/03/2010 1:27:00 p.m.	3	50
16	Deploy physical resources (damage repair)	23/03/2010 1:27:00 p.m.	1	50
17	Contact NZ Police	23/03/2010 1:31:00 p.m.	4	100
18	Define emergency scenario needs	23/03/2010 1:32:00 p.m.	1	50
19	Contact consultants	23/03/2010 1:33:00 p.m.	1	50
20	Mobilize physical resources	23/03/2010 1:33:00 p.m.	1	100
21	Mobilize human resources	23/03/2010 1:33:00 p.m.	1	100
22	Deploy human resources (management)	23/03/2010 1:34:00 p.m.	1	100
23	Deploy physical resources (damage repair)	23/03/2010 1:34:00 p.m.	1	75
24	Contact NZ Police	23/03/2010 1:38:00 p.m.	4	50

APPENDIX E – RESOURCE ALLOCATION OPTIMISATION ROUTINE CASE STUDY

A seventeen link road network and a damage scenario were used to assess the estimate resource allocation costs (i.e. logistics and response delay) according to the Logistics Model proposed in chapter 4. Both network / damage scenario and optimum results are presented as follows after the analyses of 2,900 resource deployment scenarios.

Figure E.1 illustrates the road network and associated damage scenario.

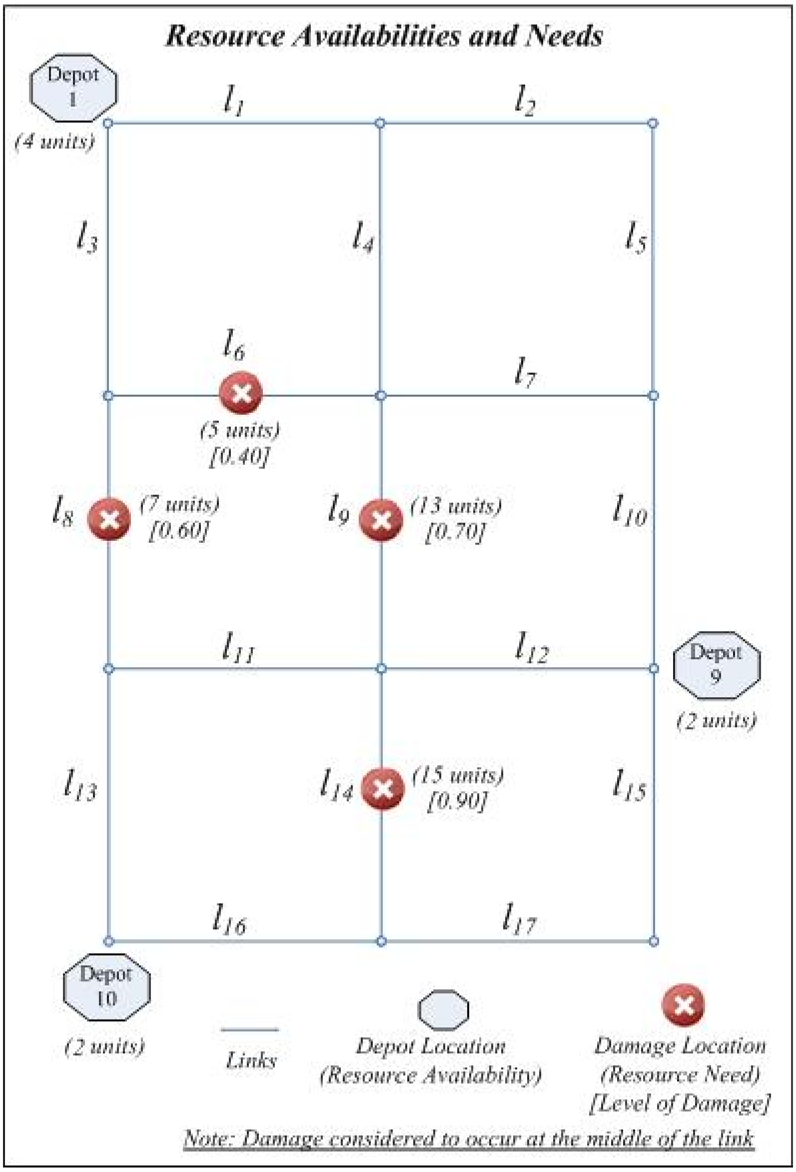

Figure E.1: Road Network and Damage Scenario.

Total Logistics Costs (*TLC*) and Delay Response Costs (*DRC*) were estimated according to the following equations (refer to Chapter 4 for further details). Final results for the thirty optimum deployment strategies are presented in Table E.1.

$$LRC^t = \sum_i \sum_j (r_{ij}{}^t * (td_{ij} * \alpha + 2LC * \beta)) \tag{E-1}$$

$$\text{Given: } td_{ij} = \sum_{a \in Pt_{ij}} L_l{}^a$$

$$DRC^t\left(R^t\right) = \sum RC_l + \sum (F_l - C_l * (1 - D_j^t)) * \theta * \frac{1}{\sum_j \sum_k \delta_{jk}{}^t} \tag{E-2}$$

		t = 1	*t* = 2	*t* = 3	*t* = 4	*t* = 5	*t* = 6
Strategy	**∑LRC**	**∑DRC**	**∑DRC**	**∑DRC**	**∑DRC**	**∑DRC**	**∑DRC**
1	2955.00	463253.79	12483.08	8656.70	5611.56	3199.38	1780.22
2	2955.00	463253.79	12876.52	9037.66	5986.56	3563.02	2138.43
3	3330.00	463253.79	10765.75	5419.19	1628.33	363.64	358.21
4	3330.00	463253.79	11185.91	6118.24	2627.88	1034.00	0.00
5	3435.00	463253.79	11049.50	5884.40	2083.17	0.00	0.00
6	2955.00	463253.79	12483.08	8656.70	5611.56	3199.38	1780.22
7	3030.00	463253.79	11989.49	7810.55	4534.64	2014.77	369.96
8	3045.00	463253.79	11989.49	7810.55	4534.64	2014.77	369.96
9	2955.00	463253.79	12483.08	8656.70	5611.56	3199.38	1780.22
10	3105.00	463253.79	11495.90	6964.40	3457.72	1034.00	0.00
11	3135.00	463253.79	11495.90	6964.40	3457.72	1034.00	0.00
12	2955.00	463253.79	12666.68	8656.70	5611.56	3199.38	1780.22
13	3255.00	463253.79	11049.50	5884.40	2083.17	0.00	0.00
14	3285.00	463253.79	11049.50	5884.40	2083.17	0.00	0.00
15	3030.00	463253.79	12382.93	8191.50	4909.64	2378.41	728.17
16	3045.00	463253.79	12382.93	8191.50	4909.64	2378.41	728.17
17	3105.00	463253.79	11889.34	7345.35	3832.72	1397.64	358.21
18	3135.00	463253.79	11889.34	7345.35	3832.72	1397.64	358.21
19	3255.00	463253.79	11679.50	6964.40	3457.72	1034.00	0.00
20	3285.00	463253.79	11679.50	6964.40	3457.72	1034.00	0.00
21	3405.00	463253.79	11049.50	5884.40	2083.17	0.00	0.00
22	3405.00	463253.79	11049.50	5884.40	2083.17	0.00	0.00
23	3420.00	463253.79	11049.50	5884.40	2083.17	0.00	0.00
24	3030.00	463253.79	11989.48	7810.54	4534.63	2014.76	369.96
25	3120.00	463253.79	11495.89	6964.39	3457.71	1034	0
26	3120.00	463253.79	11889.34	7345.34	3832.71	1397.63	358.20
27	3105.00	463253.79	11679.50	6964.39	3457.71	1034.00	0.00
28	3135.00	463253.79	11679.50	6964.39	3457.71	1034.00	0.00
29	3270.00	463253.79	11679.50	6964.39	3457.71	1034.00	0.00
30	3120.00	463253.79	11679.50	6964.39	3457.71	1034.00	0.00

Table E.1: Total Logistics Costs and Delay Response Costs for 30 Optimum Resource Deployment Strategies.