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Conceptual Dynamic Response Recovery Model for Emergency Events

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Abstract

New Zealand's State Highway Organisations (SHOs) need to work and make decisions in a coordinated and efficient manner to minimize disruptions during emergency events. The aim of this paper is to present a conceptual framework to support decision-making during emergency events based on the available information. The Dynamic Response Recovery Model (DRRM) combines practical emergency management knowledge observed from simulated emergency exercises, response procedures and an Expert System (ES) set of rules. SHOs will use the framework to improve the allocation of both personnel and physical resources during response and recovery operations. Basic premises to apply DRRM in New Zealand's context are introduced and discussed.

1. Introduction

New Zealand State Highway system is 10,837 km long and is important to the economic, social and political success of the country (Newlands, 2006). Transit New Zealand (TNZ) employs regional consultants and contractors to manage the maintenance and operation of the highway system (TNZ, 2007).

In New Zealand, highway systems are vulnerable to natural hazards and play a major role during emergency events, providing terrestrial access to affected areas and population during emergency management activities. The Civil Defence Emergency Management Act 2002 (New Zealand, 2002) emphasizes that transport networks need to be able to function to the fullest possible extent during and after an emergency event.

During emergency response, crucial decision-making is performed amongst various organisations and at different levels. TNZ interacts not only with its consultants and contractors, but also with Civil Defence and various lifeline organisations. Furthermore, TNZ response can occur at the regional and national level. A major event activates TNZ Headquarters in Wellington for national response. Alternatively, the response centre can be transferred to Auckland if the event takes place in the capital. During medium and small

events, TNZ regional offices are responsible for managing the response and report back to the national office in Wellington afterwards.

It is acknowledged that better emergency management activities can be performed through good decision-making (actions that reduce loss of lives and disruptions). Many researchers have already considered decision-making as a key component for emergency management (Cherrie & Dickson, 2006; Fu *et al.*, 2006; Liu *et al.*, 2006; Lai *et al.*, 2006; Takeuchi & Kondo, 2003). Approaches can vary in focus such as Governmental efforts (Earthquake Commission, 2007; Get Ready Get Thru Campaign, 2007; MCDEM, 2007a), systems' developments (CIMS for SAR Handbook, 2005; U.S. Department of Homeland Security, 2006) and organisation resilience (Brunsdon & Dalziell, 2005; Dalziell & McManus, 2004; Dalziell, 2005; Resilient Organisations, 2007).

However, it was not found so far a comprehensive approach to support decisions which considers relationships between the abovementioned elements. We recognize that decision-making involves different levels of information, organisations' priorities, knowledge/expertise and available technology comprising both qualitative and quantitative variables.

This paper presents a framework to help State Highway Organisations in New Zealand improve its decision-making during emergency events. After this introduction, we present the conceptual development of DRRM, which is based on an Expert System (ES) application. In the third section, we briefly describe how DRRM could be implemented for roading organisations in New Zealand. A novel method to acquire knowledge (bottleneck activity in ES development) through observing and assessing simulated exercises is described in the fourth section. The results obtained from one observed emergency event simulation are summarized in the fifth section. Finally, we draw our conclusions and future developments are discussed in the sixth section

2. Conceptual Dynamic Response Recovery Model

Decision-making activities involve cognitive tasks, information processing, data availability, cultural background and priorities among other concepts. Specifically during emergency events, decision-making has the additional dimension of stress related to life preservation and community expectations. We consider that decision-making is subject to changing conditions, multiple actors, various levels of information reliability and availability. In this context, we propose a model (namely DRRM) with the general objective of supporting decisions during emergency events. DRRM will fulfil this objective by making available to end users optimization tools, a set of rules and a friendly graphical user interface (GUI) according to an ES application in a Geographic Information System (GIS).

This section is divided into two sub-sections. Firstly, we briefly present an ES review; then, we focus on describing how DRRM is been conceptualized as a Decision Support System (DSS) and how it can be implemented.

2.1 Expert Systems

Expert Systems were derived from Artificial Intelligence (AI) studies during the sixties and seventies. Mostly, AI focuses on the simulation of human behaviour and its reasoning capabilities, but it can also be a technique for representing and managing knowledge. ES particularly has a set of rules that represents knowledge acquired from experts (Beerel, 1987; Giarratano & Riley, 1998; Jackson, 1999; Pomykalski *et al.*, 1999; Vedder, 1990).

The development of Expert Systems began with the Heuristic Programming Project which was conducted by Feigenbaum and others at Stanford (Pomykalski *et al.*, 1999). A good Expert System example is MYCIN System which uses about 450 rules to diagnose blood infections

and, at its time, was able to perform at an expert level and was considerably better than the human judgement of some junior doctors (Pomykalski *et al.*, 1999).

Four basic concepts configure what experts call fundamentals of Expert Systems: knowledge acquisition, knowledge representation, reasoning control and solution explanation. Knowledge acquisition or machine learning is defined as the transformation of potential problem-solving expertise from a knowledge source (e.g. human expert) to a computer program (Buchanan *et al.*, 1983[1] *apud* Jackson, 1999). This task is classified as the bottleneck of Expert Systems applications because it usually demands too much time due to poor productivity. After the knowledge is acquired, it must be structured in standard ways. Knowledge representation comes from the formal philosophy and cognitive psychology (Jackson, 1999). Thus, rules (syntactic and semantic) are defined using symbolic computation (or non numeric computation) and are further implemented into a computer software. Reasoning control is dedicated to how knowledge will be accessed and applied during solutions searching (i.e. processing structure). Finally, solutions explanation is focused on specifying processes and reasons used to achieve results.

ES are divided into two major components: Knowledge Base and Inference Engine (Figure 1). The application runs according to an integrated relationship between the user and the system. Users have to provide facts or data so the system can operate. The Knowledge Base (i.e. special data base which contains the means to collect, organize and retrieve knowledge) has a set of rules, which represents the expertise previously acquired from experts during the development phases. The Inference Engine is the software application responsible for processing facts/data using those rules. Finally, the Expert System returns expertise (i.e. processed facts/data) once the processing phase is over.
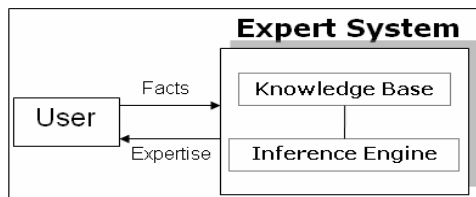

Figure 1: Expert System Structure (Giarratano & Riley, 1998)

2.2 DRRM Framework

DRRM is focused on presenting and analysing data about emergency events and creating useful information for decision-making. SHOs' expertise and optimization procedures are considered in order to create a hybrid Decision Support System and Knowledge-based system. DRRM combines practical emergency management knowledge acquired from experts via either real or simulated events; *ad hoc* response procedures; and vulnerability/reliability indicators.

The framework is divided into two approaches according to the concepts of DSS and ES. In this research, DSS are considered as applications without complex processing routines. The focus on presenting data and/or information in a way that users can extrapolate and make decisions, while ES emulates reasoning capabilities performed by human experts through rules in a Knowledge Base.

The first DRRM stage makes use of Communication, Data and Document-driven DSS focusing on bringing together two components to aid decision-making: Data Base

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[1] Buchanan B. G., Barstow, D. Bechtel, R. Bennet, J. Clancey, W. Kulikowski, C. Mitchell, T. M. and Waterman, D. A. (1983). *Constructing and Expert System.* In *Building Expert Systems* (Hayes-Roth F., Waterman, D. A. and Levat D., eds), Chapter 5. Reading MA: Addison-Wesley.

Management System (DBMS) and Expertise Base (Figure 2). The DBMS will use a GIS application to represent in a map format different sources of information: State highway asset database; New Zealand map database (state highway network, territory, regions, urban areas, cities); and Road network vulnerability database. The Expertise Base will contain general planning activities (represented in a decision tree format) which will help organisations to reduce the time necessary to plan strategic operations (response actions to be taken during the event). Planning activities will be based on available general information about the event until precise information is acquired (i.e. during the event warning, occurrence and observation). For instance, an organisation which relies on fuel availability to conduct its activities will receive a recommendation to plan fuel requirements for extreme cases, such as, major cyclone/flooding which will have anticipated long term effects.

The second stage (conceptualized as a model and knowledge-driven DSS) has complex processes focusing on optimization procedures and reasoning capabilities (Figure 2). The optimization procedure will process network reliability indicators as measurements of vulnerabilities in order to produce decision-making information for the transport sector. This will be done by combining damage information among the data sources from the DBMS. The output will be a prioritization of which assets must be fixed first taking into consideration time, reliability and resources costs (human and physical). The emergency response knowledge will convert optimization results into a set of actions and repair plan (i.e. recommended actions). This processing has the aim of emulating the experts' reasoning capabilities regarding how decisions are made based on human expertise and available information.
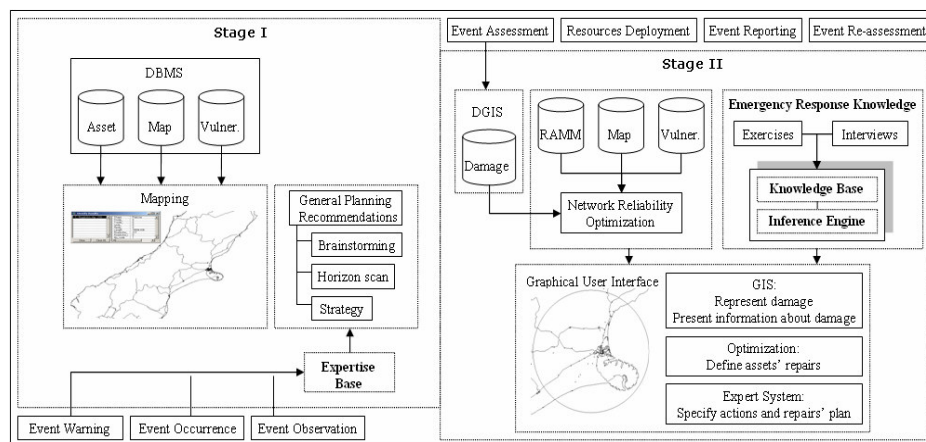

Figure 2: DRRM Framework.

DRRM development has two major activities running in parallel. One is focused on applying existing concepts of GIS/mapping, vulnerabilities and network reliability. The other activity is the development of an original decision-making theory for emergency events based on qualitative analysis of experienced exercises, real events and interviews. DRRM System will also be a flexible application allowing end users to fully or partially follow/use recommended actions and processed information. In this context, SHOs will also be able to process their own queries using specific optimization tools.

3. DRRM for Roading Organisations in New Zealand

A route priority application will be developed specifically for roading organisations in New Zealand. The application will focus on network vulnerabilities, risks assessment, Geographic Information System (GIS) and knowledge management. In this context, given a set of information conditions, the application will be employed for making recommendations on response plans and actions; for presenting information about route vulnerability; and for

determining the allocations of resources in order to minimize disruptions during various events' phases.

The application follows DRRM framework and has two operational stages. The first stage will mainly be operational while general data about the event is available. The application is useful for SHOs before and immediately after the event begins. This is a period in which organisations, communities and people are focusing to preserve life and to define readiness/response plans. The system will prompt general planning recommendations for decision makers. Also the user will have access to information about network vulnerabilities for individual links or selected routes and assets' information. Vulnerabilities for each link will be calculated according to defined Index (links' characteristics) and Hazards Matrixes (risks for links' characteristics considering the event). Stage I of Figure 3 roughly represents how results could be presented for Stage I.
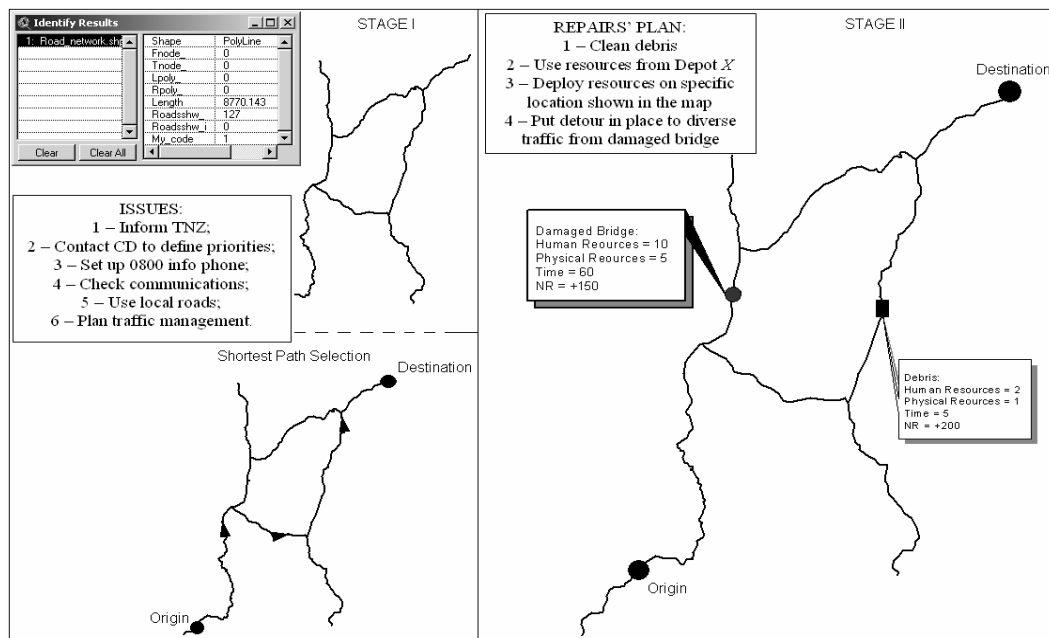

Figure 3: Operational DRRM – Stage I & Stage II.

The second stage starts running after data about damage, affected areas and population, priorities and resources become available. At this stage, the user will be able to visually identify damaged links and associate repair costs in terms of time and resources. The application will estimate the network reliability according to an optimized strategy to conduct repairs throughout the network. Thus, a repair's plan (the estimation of time to conduct repairs and human and physical resources allocation) is defined using an Expert System application that is, network reliability parameters and rules. The flexibility of the application will also allow the user to define its own repair plan in order to meet external organisations' priorities. In such cases, the application will return estimations for each parameter used in the optimization (time, resources, and reliability) and a set of recommended actions to meet the plan defined by the user (Stage II of Figure 3). Furthermore, a set of decision-making tools to generate information to help the decision-making will be available to users (e.g. affected population and hosting facilities).

Finally, a key task in the DRRM development is the knowledge acquirement. In this context, emergency exercises are very useful. Practical knowledge acquired from exercises observations can be analysed and variables, information needs and the patterns of interactions amongst emergency response players can be identified as well as decision-making components.

4. Observing and Assessing Emergency Exercises

In New Zealand, simulated exercises such as Pandora (MCDEM, 2007b), Ruamuoko (Civil Defence, 2007), Marconi and Capital Quake are a common practice. They are used to develop knowledge about emergency response within communities and organisations (e.g. Transit New Zealand, Ministry of Civil Defence and Emergency Management – MCDEM, Ministry of Health and Civil Defence – CD) and to build up a resilient country. In this context, a method to observe and assess emergency exercises was developed taking advantage of usual simulated exercises. The general procedure in divided into two stages as follows. The first stage is divided into six steps:

- Step 1: Search appropriate upcoming exercises throughout the country.
- Step 2: Once an exercise is identified, contact organisations responsible for organizing the exercise, in order to check the possibility to take part as observers.
- Step 3: If the participation is authorized, then learn the dynamics involved in the exercise and identify participants, objectives, major players, scenario and injects.
- Step 4: Develop survey forms to collect data and arrange all necessary recording media;
- Step 5: Conduct the observation itself with the aim to record all possible information for example communication, decision-making, injects, debriefing discussions and facilities.
- Step 6: Produce a report containing the exercise flow, key decision-making, available facilities and important findings/conclusions for Resilient Research project.

Note: It is also expected during the exercise to develop contacts with key decision-making personnel within the organisation so future surveys can be carried out.

The second stage (re-enacting/assessing) takes place once the report is produced. The re-enactment is conducted by the Resilient Organisation Team through replicating the exercise. A similar survey to Step 5 is carried out by recording all the actions taken by the Resilient Organisation (ResOrg) Team so that a comparison between the decisions taken by both teams can be conducted in order to assess the procedures and the reasoning used. The aim is not to compare performance nor to identify strengths and weaknesses in response actions taken by each organisation/team, but to assess different approaches for emergency responses so that good decision-making procedures can be designed and implemented in DRRM's knowledge base.

5. Results Obtained from Exercise Observation

This section describes the Marconi Exercise simulated on 8th of June 2007 in Auckland, New Zealand. It also presents findings from the observation and re-enactment, which helps to develop DRRM's knowledge base specifically for New Zealand's State Highway Organisations.

5.1 Marconi Exercise 2007

The Marconi exercise was a distributed tabletop exercise for the assessment of communication and information transfer. The Auckland Region exercised coordination and communication between lifeline utilities and CDEM centres. The exercise focused on the response phase for a major emergency and it was led by the Auckland Engineering Lifelines Group which represented transport, water, energy and telecommunication. Auckland CDEM Group was also involved.

The base scenario was an extreme weather event (tropical cyclone) causing significant damage and flooding in the Auckland Region. In the transport sector, the damage and the scenario consisted of high wind gusts (up to 170km/h); heavy rainfall of at least 450mm; heavy sea swells and inundation; and major flooding on the State Highways and on the main arterial

routes. Widespread and prolonged power outages with uncertain times for service restoration, possible shortage of fuels and telecommunications related impact were also considered.

The overall aim of the exercise was to review and improve the lifeline utility coordination response processes. Specific objectives were to review lifeline utility co-ordination processes in the Group EOC (Emergency Operational Centre) through escalating levels of emergency (culminating in a Group Declaration); and to assess the lifeline utility interface with the Group EOC with focus on communication and information transfer. Beyond these objectives, lifelines utilities were free to test their own response plans during the exercise.

5.2 Observation and Findings

The whole observation was conducted following Steps 1 to 5 described in the previous section. Analyses were based on Step 6 and the exercise re-enactment. During the observation, the team acquired data in a way that it could be retrieved and processed into useful information for developing a knowledge base for DRRM. Findings from the simulation were then compared with those acquired from the re-enactment in order to identify decision-making in a broader spectrum.

The exercise was ruled by Lifeline Utility Response & Recovery Protocols regarding communication and information transfer between Lifeline Utilities and Group Emergency Operational Centre. The CDEM Public Information Management Group ruled media and public communication. Finally, TNZ personnel had available the "TNZ Emergency Procedures Manual: Region 2" and the Priority Routes for Auckland Region (AELG, 2005).

During the exercise, Lifeline Utilities were required to perform in at least two different phases: Impact assessment & Communication to LUC; and Pending issues & Report implications, needs and priorities. In the first phase, TNZ did not make use of the contractors and did not liaise with the police or other organisations to control the roads. Also, the impact assessment was conducted based on damage presented in the injects received (i.e. search for additional information was not performed), which was summarized on laminated maps. TNZ staff start the second task in the first phase (reporting back) after all information was summarized on the maps. In this context, a simple decision-making discussing took place and decisions taken were then written in a template report (namely, Lifeline's Utility Report) provided by the Lifeline Utility Coordinator (LUC). TNZ mainly concerned on closing roads until high winds and heavy rain fall ceased so repairs (e.g. vehicle removal, pylon removal, debris cleaning) could take place. No alternative ways to manage the roads, divert traffic or define/inform alternative routes were discussed showing once more that TNZ was focusing on checking communications among other organisations involved in the exercise.

In the second phase, organisations were required to identify main interdependencies using a compiled Lifeline Utility Report produced by LUC which contained information about all lifelines involved in the exercise. In this phase, TNZ's staff updated with new information the initial Lifeline Utility Report; they discussed fuel requirements issues; they checked communications with one contractor and the central city office via radio; and they made use of fax communication in order to check out its usefulness during an event.

During the re-enactment, the Resilient Organisation Team was asked to play TNZ's role. Firstly, a brief presentation about the exercise itself and its objectives took place. Same injects used during the exercise were presented and notes about responses and planned actions were recorded. Table 1 summarizes the experience during both the exercise and the re-enactment.

It was possible to make a great variety of comparisons using Table 1. This activity was valuable as TNZ exercised coordination and communication and the Resilient Organisation Team focused on decision-making for preparedness and readiness. These two approaches were complementary for this research and lessons for both communication and decision-making

issues were learnt. In this respect, the exercise and the re-enactment presented different outcomes. However, each one has its importance for the development of the knowledge base since decision-making is dependent on both information collecting/sharing (using various communications' technologies) and procedures/expertise. Finally, it is clearly shown in Table 1 that many issues to be considered during an emergency event were identified using the proposed observation method.

<p align="center">Table 1: Summary of Findings from Marconi Exercise and Re-enactment</p>

		Marconi Exercise (TNZ)	Re-enactment (ResOrg)
Communication	Technology	Up to date (radios, Internet connection, phones, fax and satellite phones).	N/A
	Procedures	Fixed and pre defined by AELG and Lifeline Utility Coordinator – Standard Lifeline Utility Report	N/A
	Coordination	Centralized by the LUC.	N/A
Information Technology Systems	Hardware	Traffic cameras.	N/A
	Software	*i*) SCATS. *ii*) Computer-based GIS non operational.	On going research on an integrated IT application using GIS and DSS/ES.
Decision-Making	Preparedness	Superficial not considering all available information.	Extremely complex considering a great range of possible related impacts (resources mobilization; communications checking; alternative routes; hourly reporting; etc)
	Response	Suitable with the detail of information received (e.g. close bridges due high winds and traffic accidents; close roads due to blockages; etc)	Response considering responsible organisations to manage specific situations (e.g. pylon removal) and liaise with other utilities.
	Recovery	N/A	N/A
Debriefing Discussions	Decision-Making	General decision-making actions considering available information	Actions and planning considering available information and possible sources of information. Planning focused mainly on readiness.
	Communication	Discussions about Public Information and information sharing among organisations adopted by LUC.	N/A

During the Marconi Exercise, TNZ was looking for the best and alternative ways of communication in the case of a power shortage. Questions were raised about power availability and possible consequences on communication (internet, radios and mobile phones), internet/e-mail overload and the operability of traffic cameras (CCVT cameras) and Variable Message Signs (VMS). Communication with the public and media was identified as a high level of importance. Staff were aware of the importance of the coordination of media

releases and communication at both local and regional levels. However, during the re-enactment, communications issues were not a main topic due to limitations on the way the re-enactment was conducted. It is acknowledged, nevertheless, as a key factor by the ResOrg team, so DRRM is being currently designed as a common information system in which different organisations will be able to access all data/information and update some accordingly to its "restrictions".

As already mentioned, missed opportunities regarding decision-making activities were identified on TNZ's performance. In general terms, TNZ used the exercise to check information flow and communication protocols, which was the major objective of the Marconi Exercise. Complex decision-making efforts were not observed and staff did not use TNZ's plans and procedures, but instead they used own expertise and experience. However, we have to reinforce the fact that the exercise aimed "to review and improve the lifeline utility coordination response processes" and not to improve response procedures. Resilient Organisation Team had a strong focus in decision-making on a strategic level. Hence, a well defined set of variable and priorities can be extrapolated by analysing both TNZ and Resilient Organisation Team performances.

Debriefing meetings were mainly to discuss uncertainties regarding lack of data. Confusing situations were faced as injects were superficial in terms of data. We did not experience discussions on how to improve information sharing and decision-making during the exercise, but an informal discussion after the exercise has shown that TNZ already has a basic GIS and a good understanding on how to help decision-making during emergency events.

6. Conclusions and Future Developments

Many lifeline utilities are dependent on road transportation to carry out their response activities (AELG, 2005). A DSS application for SHOs is valuable because response actions and resources deployment can be improved during emergency events. To do so DRRM must be embedded with emergency response knowledge. In this context, exercise observation is a key activity for DRRM development. The observation method showed to be an efficient manner to learn how decisions are taken during emergency events and what the key decision-making variables are. Also, some deficiencies were identified as well the role of the re-enactment considering the research's context.

The framework is compatible with New Zealand's context regarding to existing resources such as the main State Highway's assets data base (RAMM), emergency exercises and public and private organisational efforts. Marconi exercise was the start point in the development of DRRM's knowledge base. Its contribution to define rules for emergency response in the future looks promising.

Finally, we envisage different challenges to continue the present research. As part of our future development plan we highlight: *i*) More specific observation method regarding activities in step 5; *ii*) Refined DRRM Framework based on a depth DSS and ES literature review; *iii*) More observations to identify different decision-making components; *iv*) To develop an interview structure to be conducted with key personnel in order to acquire specific emergency management knowledge; *v*) Represent knowledge acquired in terms of rules within a knowledge base.

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