Enhancing the reconstruction process for road networks: opportunities and challenges for using Information Technology

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Abstract

Post-disaster reconstruction of roading networks is a notoriously complex task that involves prioritisation and allocation of resources, as well as extensive information gathering and sharing of information between the involved organisations. Advances in Information Technology (IT) have prompted various initiatives using simulators, damage scenario tools, Geographical Information Systems (GIS) and Decision Support Systems (DSS) to assist post-disaster reconstruction preparedness. This paper presents a critical overview of how Information Technology was used in the reconstruction process of the road network in Southern California after the 1994 Northridge Earthquake and how international organisations cooperated with national and local organisations to support response and recovery to the 2004 Sumatra Earthquake and Tsunami. Both events are analysed in order to identify the driving criteria that have ruled the repair/reconstruction processes. Thus, opportunities and challenges to employ IT for roading organisations to support post-disaster reconstruction are discussed based on the analysis of real events previously mentioned.

Keywords: Road Networks; Information Technology; Prioritisation; Resources; Decision Making.

Introduction

Organisations have to work in a collaborative way in order to recover from extreme events in disaster prone countries. A great variety of activities is expected to be restored or to continue to function after a disaster, thus organisations involved in emergency management activities must be resilient and have to be able to activate their business continuity plans as soon as practicable. The main objective is ensure that essential services continue functioning, albeit at a reduced level, following a major disaster. The ability of organisations to effectively respond following an event has a great influence on the length of time that affected essential services (e.g. power, telecommunications, gas, water, wastewater, sewage etc) will be unavailable, and therefore on the total social and economic impact experienced by the community following a hazard event.

The roading network plays a vital role to community response and recovery as many organisations are dependent on road access to carry out their own response and recovery activities (AELG, 2005). Furthermore, emergency services and organisations needing to transport resources to support the response and recovery effort require accurate and up to date information about the availability of routes.

The range of issues to be considered increases, even more, during the reconstruction phase as different organisations and players (i.e. interested parties) promote their specific requirements into the decision making process. Thus, roading organisations and decision makers often have to analyse multiple and complex sets of interests before establishing priorities and managing available resources. A clear understanding of the information needs, to perform decision making tasks such as the ones previously described, is still missing.

This paper examines the potential for deploying Information Technology to support stakeholders and decision makers during post-disaster reconstruction activities. It is envisaged that comprehensive information about available human and physical resources, traffic flows, risks/vulnerabilities, damage and organisations' priorities can support the decision making in defining repair-sequences for the damaged road components. In particular, this paper focuses on the implementation of Geographic Information Systems, GIS, Decision Support Systems, DSS, and Expert Systems, ES, in being ready for response and recovery on the road network.

After this introduction, the second section presents a critical insight into how GIS and DSS might be used for post-disaster reconstruction. The third section uses real events (1994 Northridge earthquake in Los Angeles, United States of America and 2004 Sumatra earthquake and tsunami) to identify the driving criteria that have ruled past repair/reconstruction processes. The fourth section is dedicated to discussing a wider perspective for post-disaster reconstruction of roading networks and the conclusions and future developments are underlined in the last section.

The Role of Information Technology in Post-Disaster Reconstruction

Information Technology, IT, undoubtedly, plays an important role for post-disaster reconstruction processes. It provides means to collect, process, analyse and share data/information. In this respect, different techniques have been recently researched in numerous fields of knowledge. This section describes how tools such as Geographic

Information Systems, Network analysis, Decision Support Systems and Expert Systems can contribute in managing post-disaster reconstruction.

Geographic Information Systems and Network Analysis

The introduction of Geographical Information System based tools to support the decision making process, during and after crisis events, can potentiality increase the situation awareness of decision makers. An increased level of situation awareness can improve reconstruction processes as knowledge from several fields and organisations can be represented in different layers in a common mapping format. In general terms, for post-disaster reconstruction GIS would effectively organise and display information about: a) the highway network and its structural components; b) the affected network's components and specific damage experienced; c) the most vulnerable assets; d) the repair priorities; and e) the location of available physical and human resources.

GIS is actually an "*ad hoc*" tool that stores fundamental information and delivers maps in a format that can be easily read and consulted. It also provides more flexible spatial analysis tools that require more training to be used, but can produce complex and strategic decision making information. The availability and clear representation of the aforementioned information has a key role in the reconstruction phase where the aim is to achieve the best results using the minimum of resources and time. For example, within the transportation sector, GIS can be integrated with network analysis to increase the probability of a network remaining connected after a disaster (Nicholson, 2007), for optimizing tolling design considering travel time (Li et al., 2007) and for defining routes for hazards materials transportation (Nagae and Akamatsu, 2007) among others applications.

Integration of a GIS based tool and network analysis techniques seems to be promising for post-disaster reconstruction. Once the location of available physical and human resources are known (considered as the origin points) and the site of damage / emergency repairs priorities (considered as the destination points) are identified/visualised, a network analysis can be performed allowing the recovery performance (in terms of congestion, detour lengths, restoration times etc) to be optimised by comparing different repair sequences.

For different purposes, simulation exercises implementing GIS and network analysis based scenarios, could be used as training tools to increase the situation awareness of decision makers. Such activities would be essential in developing response skills by practically testing and measuring the impact of different decision on the roading network performance and consequently on access by emergency services, restoration of other lifeline utilities etc.

Relevant examples of tools combining the use of network analysis and GIS to support extreme event decision making can be found in the international literature. As an example, the use of Information Technology solutions for improving the emergency response capabilities of first responders has been recently explored by the RESCUE project (Mehrotra *et al.*, 2004), a joint research programme between the University of California at Irvine and the University of California at San Diego. An Internet-based Loss Estimation Tool, INLET has been developed as part of the RESCUE project in order to provide real-time estimation of damage scenarios and transportation simulation after an earthquake (Huyck *et al.*, 2006). A methodology for enhancing post-earthquake

emergency response for highway systems has also been developed under a FHWA-MCEER joint research programme (Multidisciplinary Centre for Earthquake Engineering and the Federal Highway Administration in USA) resulting in a software package named REDARS, Risks from Earthquake Damage to Roadway Systems (Werner *et al.*, 2004). Further references of researches using ether solo or combined GIS and network analysis are Cherrie *et al.* (2006), Fu *et al.* (2006), Liu et al. (2006 a), Liu et al. (2006 b) and Takeuchi & Kondo (2003).

Decision Support Systems and Expert Systems

Decision Support Systems, DSS, and Expert Systems, ES, have slightly different definitions, even though their objectives in the context of decision making are similar. On one hand, DSS generally incorporate a broad range of systems that facilitate decisions by helping the decision maker to respond quicker to changing needs (Power, 2005). This definition includes a great variety of systems such as data warehouses, optimisation models, visual simulations, risk analysis packages and GIS. On the other hand, ES are defined as computer systems that improve decision making by representing knowledge and emulating reasoning abilities inherent to human experts (Siler & Buckley, 2004; Pomykalski *et al.*, 1999; Beerel, 1987 and Giarratano & Riley, 1998).

In the context of post-disaster reconstruction, both techniques have great potential. As management tools, they can be used to facilitate the decision making after crises events in order to optimise the deployment of available human and physical resources. They also offer the possibility to estimate resource needs according to complex damage information. Thus on one side of the spectrum, the management of a great variety of information is possible. On the other side, complex activities can be performed by processing information using the knowledge represented by the rules within an Expert System. Either way, the decision making can be improved as more information and complex scenarios are considered before actions are taken and different users' needs are fulfilled.

It is possible to foresee various DSS and ES applications for post-disaster reconstruction. Some applications have already been researched in different fields of knowledge. For instance, gaming simulation and group decision support systems were assessed for decision making after extreme events (Mendonca *et al.*, 2006); Fredholm (1999) studied cognitive models (i.e. knowledge-driven DSS or ES) for emergency management and practical knowledge for crisis management was analysed by Vedder (1990). However, Information Technology applications for post-disaster reconstruction are still missing as research has been generally broad (i.e. different types of organisations are considered). Specific approaches considering information needs and a comprehensive cultural background are needed in order to achieve an efficient application that can be easily manageable to deliver useful decision making information to emergency organisations.

Post-Disaster Reconstruction Analysis of real events

Northridge Earthquake – January 17, 1994

On Monday, January 17, 1994, at 4:30 a.m., an earthquake of a magnitude of 6.8 shook Los Angeles, California. The earthquake damaged 114,000 residential and commercial structures spread over 2,100 square miles, took 72 lives and significantly impaired the Los Angeles regional transportation system. The highway destruction caused by the

earthquake was a significant strain on the auto-dependent Southern California. Being an important factor in the region's mobility, the highway system concentrated great deal of attention and transportation agencies quickly responded to the damage. The Guiding Priority of the reconstruction process after Northridge earthquake was to ensure "Mobility". In this context, the dependence of the Los Angeles population on the highway network underscored the importance of the transportation agencies to restore the regional mobility as soon as practicable.

The Department of Transportation (Caltrans) can be highlighted as the major organisation involved in the response process to the Northridge Earthquake among numerous minor and medium roading agencies. Caltrans led the successful reconstruction effort and made two key decisions quickly after the earthquake: a) to rebuild the damaged freeways, and b) to retain traveller mobility and keep traffic flowing as smoothly as possible during the rebuilding efforts.

With the lead of Caltrans, this costly disaster became a model of incident management (DeBlasio 2002). Key elements of the successful incident management have direct connections with the readiness and the flexibility of the decision making performed by Caltrans. As a matter of fact, the reconstruction process of the highway system began on the first day after the earthquake. They used emergency contracting procedures (mainly "handshake" agreements) to immediately begin debris removal and demolition activities. Short term actions were also taken to re-connect the network by implementing detours using available maps from existing management plans.

Furthermore, the successful management would not have been possible without the coordination capabilities of the different responding agencies and authorities involved. The use of Information Technology was essential and it had to be widely implemented. In this respect, the Caltrans Traffic Management Centre (TMC) was wisely adopted as the centre for initial decision making efforts and all coordination of traffic operations was performed there on the day of the earthquake. Caltrans also led the coordination of the transportation response with the Federal Highway Administration (FHWA) and took responsibilities to monitor traffic in intersections within Los Angeles with the City Los Angeles Department of Transportation (LADOT) by using its Automated Traffic Surveillance and Control System (ATSAC).

Finally, a key element of the successful management of the reconstruction process can be identified as the situation awareness of decision makers about their limitations and consequent proactive adaptive capacity. While the TMC was very functional, its technological capabilities were known to be limited for real-time decision-making purposes. The same was true for the ATSAC system. Also extensive traffic management capabilities (such as speed monitoring loop detectors, closed circuit television – CCTV, on-ramp meters, variable message signs – VMS) were available on most of the major freeways, however many of the areas affected by the earthquake did not have Intelligent Transportation Systems (ITS) technologies in place. In order to cope with these limitations (on the day of the earthquake) Caltrans and the LADOT immediately began strategising about ways to upgrade facilities in order to handle the possible overload of Caltrans TMC and ATSAC.

To effectively respond to this need, three months after the event, the Earthquake Planning and Implementation (EPI) centre was opened and acted as a hub for many advanced technologies that facilitated the traffic management in the disaster areas. The

goal of the EPI centre was to focus on communication between transportation agencies and emergency officials and commuters, providing accurate important information for those involved. Thus, the EPI centre was vital in coordinating traffic management deployments and giving accurate and immediate information to traffic engineers. This assisted them in making better decisions and collecting information about the changes in the traffic behaviour over time during the reconstruction phase.

The conclusion stated in the previous paragraph is further endorsed by a Transportation Research Circular (published by the Transportation Research Board http://www.trb.org/) in which it highlighted that the availability of accurate traffic data was critical in developing emergency detours. It also noted that areas with well-developed traffic management centres were able to accommodate sudden traffic changes more easily.

Sumatra Earthquake and Tsunami – December 26, 2004

On the morning of December 26, 2004 a magnitude 9.0 earthquake deformed the ocean floor near the Indonesian island of Sumatra. The event pushed the overlaying water up into a Tsunami wave that devastated numerous areas and killed nearly 250,000 people (Earth and Space Sciences, 2008). According to the Russian Institute of Computational Mathematics and Mathematical Geophysics (2008) citizens from 55 countries were killed and more than 5 million people were affected, including more than 1 million homeless.

Although the international and national response to the disaster was rapid and financial aid adequate, poor coordination of the response made the decision making process more difficult. In general terms, coordination efforts have not performed very well because of the diversity in information accuracy provided by the different countries affected in the disaster. In addition, social and political issues as well as damage to critical infrastructures further limited information availability.

The size and rareness of the event added another variable in the response process as damage varied considerably between affected areas. For instance, some beaches in Thailand were reported re-opened after 4 days while other areas (e.g. the Province of Nanggroe Aceh located near the epicentre) shifted into reconstruction and rehabilitation only six weeks after the event (Kawata *et al.*, 2005).

On an international level, it was clear that there was a crucial need for coordinated, up-to-date information about the damage scenario, the allocation of resources, the position and distance of essential structures and of strategic facilities, in order to effectively coordinate the large number of agencies responding to the disaster world-wide. All these needs could have been fulfilled by the implementation of GIS technology. For this reason, many local and international agencies focused on providing necessary GIS data that could be easily understood and shared. However, reconstruction personnel were not trained to interpret and use the full potential that GIS data offers, including the dynamic dimension that could be explored within a GIS platform. A few examples of GIS used during the 2004 Sumatra Earthquake were:

- International Water Management Institute (IWMI) in Sri Lanka and Cornell University: use of Manifold$^{®}$ interactive mapping technology (www.manifold.net) as illustrated in Figure 1 to publish online within hours after the tsunami important data so it could be accessible by any user (most of the data came from the Tsunami Satellite Data Catalogue);

- GeoSpatial Data Sharing Platform for Asia Tsunami Rehabilitation (CGIAR-CSI): supported information exchange for Tsunami related rehabilitation and reconstruction efforts. Designed as a platform to provide easy access to a variety of geospatial data for the affected regions.
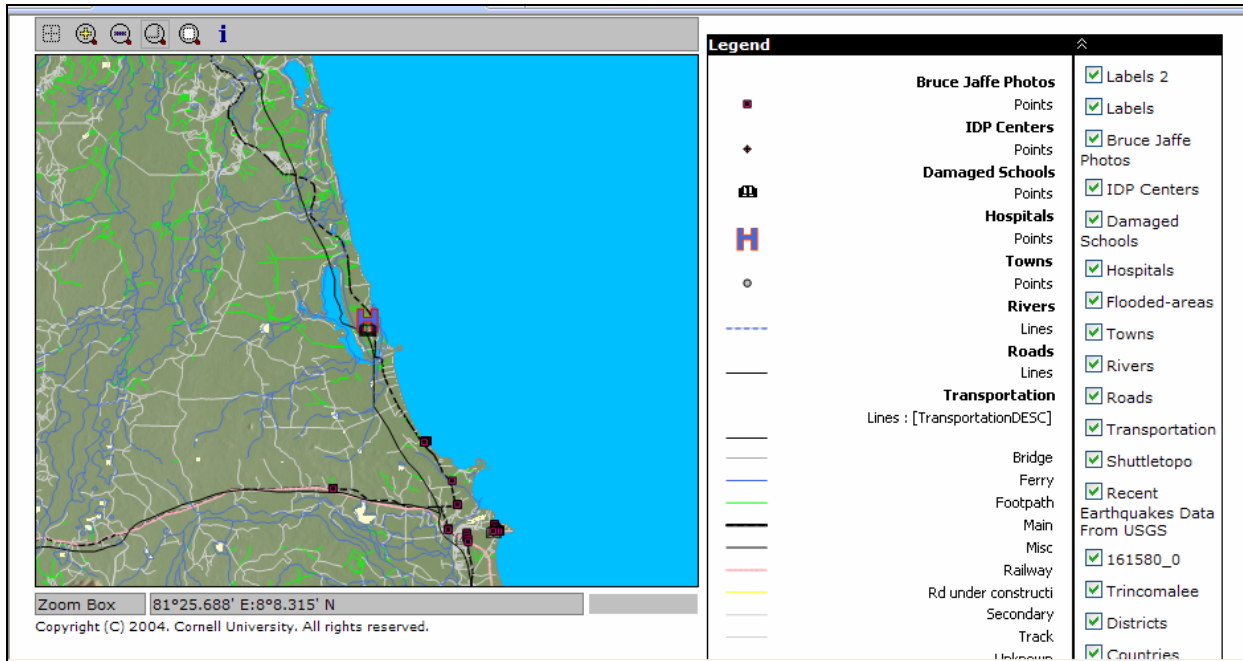

Fig. 1. Manifold® Platform Representing Phuket Beach in Thailand and Vakarai Hospital. Source: www.polarbear.css.cornell.edu/srilanka/default.asp

The Asian tsunami triggered the first emergency deployment in the short history of MapAction, a charity in the United Kingdom that supports humanitarian operations through the provision of data collection and mapping capability in the field. It does this by gathering pre-disaster mapping data, downloading remote-sensing imagery and sharing it via communication satellite, Internet or phone. Figure 2 shows how MapAction would work in a real event so geo-spatial data can be made available to decision makers. In the specific case of the 2004 Sumatra Earthquake, the MapAction team was mobilised within 48 hours and spent three weeks in Sri Lanka working alongside national and international aid agencies and Non Governmental Organisations in order to help acquiring and sharing information.

Fig. 2. Methodology Adopted by MapAction to Provide Real Time Mapping Capabilities Emergency Response Activities. (Technology Usage Diagram implemented by MapAction downloaded from www.mapaction.org)

Interesting examples of international support in providing information and IT technologies in the aftermath of Sumatra Earthquake can be found in the actions performed by the United Nation Office for Humanitarian Affairs (UNOCHA). It provided information products and management tools for the response process. Furthermore, the Humanitarian Information Centre (HIC) under the UNOCHA coordination provided humanitarian services to communities in Sumatra, Sri Lanka, and the adjacent countries. Along with a number of partners (e.g. United Kingdom's Department for International Development – UKDFID and the humanitarian aid department of the European Community Humanitarian Office – ECHO), it made available a diversity of products such as coordination tools, maps, world wide web and related services, technical support, survey design, data archiving etc. These actions represented the main source of information for decision making in Sumatra and contributed to a common framework for information management within the humanitarian community. The main products delivered were maps representing activities in the food sector, internally displaced people, health and education camps, road network, locations of the NGOs etc (ESRI 2006). Over time, response activities gradually shifted to a proper reconstruction process and HIC changed its approach to solely support the Indonesian Government in its specific needs. This fact showed considerable flexibility within the HIC, which is now called United Nations Information Management System (UNIMS) and cooperated with the United Nations Recovery Coordinator for Aceh and Nias (UNORC) during the reconstruction process in Indonesia.

A Wider Perspective for Post-Disaster Reconstruction

From the analysis of the events presented in this paper it is clear that Information Technology has been used for post-disaster management, however it could be further explored in order to achieve more successful applications. Northridge and Sumatra examples give us a good insight on how to improve the use of IT in disaster management as they differ in size, consequences, response capabilities and resources (one event has

happened in a developed country while the other affected poor and developing areas in many countries).

Caltrans' experience in the 1994 Northridge Earthquake has shown that IT devices such as traffic volume detectors can facilitate decision making if wisely planned and used. Moreover, the 2004 Sumatra Earthquake and Tsunami proved that global organisations can support local activities through the use of the world wide web (Internet) due to its simplistic operation as well its diffusion in many fields of knowledge and among different professionals (e.g. engineers, doctors, managers, politicians, planners). It also has proven to be surprisingly suitable for emergency management activities as great volumes and different types of information (e.g. satellite images, documents, pictures, reports, voice) can be acquired and shared amongst all players.

However, specialised IT systems such as Geographic Information Systems and Decision Support Systems have been misused, neglected or not even explored. This can be a consequence of the need to have specialised knowledge to operate those systems. This could be associated to the fact that research and development might not have been effectively reaching reconstruction practice. Thus, the availability of IT is not enough to achieve high levels of efficiency. IT solutions need to be designed with a clear understanding of real decision maker's needs, and whose implementation capabilities can be clearly demonstrated.

Consequently, a great window of opportunities is currently open for developing and implementing new IT approaches for emergency response. Research focusing on defining information needs, organisations' roles in the disaster context, planning and practicing emergency procedures, developing an understanding of resilience etc must be encouraged by governmental agencies and research institutes. Dantas et al. (2005 and 2007) have conceived an effective model to share information amongst decision makers called Dynamic Geographic Information System (DGIS). Complementarily, a Dynamic Response Recovery Tool (DRRT) is under development so the DGIS will be embedded with decision making support capabilities like network analysis and resources allocation optimisation routines (Ferreira et al. 2007).

Conclusions and Future Developments

Many opportunities rise from the combined analysis of real events and Information Technology concerning post-disaster reconstruction issues. It is clear that information plays a major role as it is a key "factor" for making decisions after a disaster. Priorities assessment can be improved if accurate and up to date information is available. Hence, an efficient allocation of human and physical resources is expected.

A strong information based framework is necessary to assess risks and to inform both decision makers and the impacted community. Developing situation awareness and pre-planning response and recovery actions for the aftermath a disaster is an effective way to be ready, and to increase the likelihood of using available resources wisely. These issues have to be carefully assessed for road network reconstruction decision making as roading transportation plays a major role during emergency management. Hence, the efficient management of resources is fundamental to quickly achieve the goals established in the response and recovery plans.

This paper has proven that initial developments in using IT for the purpose of emergency management have already been taken. After a major disaster, decision makers, rescue agencies, and civil defence managers need quantitative and qualitative estimative of the extent of the disaster. To overcome such an issue, technology can help in many ways:

- Highly developed databases and emergency management systems used in developed countries must be available for developing economies as well. For instance, databases were not readily shared because of political issues. Communication and high-resolution satellite imagery proved invaluable in the Indian Ocean countries after the 2004 Sumatra earthquake and Tsunami;
- Satellite images, maps and other geo-spatial information in appropriate format and definition contain vital information for emergency response and recovery;
- GIS applications must be pre-designed, including specific needs previously surveyed in different areas worldwide. It is necessary to understand that different countries and cultural backgrounds mean different information needs. For example, configurations that work in the USA might not work in New Zealand due to different organisational structures; and
- The use of technologies (GIS, DSS, scenarios and simulations) through training can develop an understanding of the risks, vulnerabilities, preparedness and readiness which are essential for effective decision making after a disaster. Concepts of resilience must also be developed within organisations responsible in providing essential services.

References

AELG – Auckland Engineering Lifeline Group (2005). *Resources Available for Response and Recovery of Lifeline Utilities*. Technical Publication No. 282 (Version 1.0). ISBN: 1-877416-02-9. Auckland Regional Council, Auckland, New Zealand.

Beerel, A. C. (1987). *Expert Systems: Strategic Implications and Applications*. Ellis Horwood Limited. England. ISBN: 0-7458-0251-6.

Cherrie W. W. Ng & Dickson K.W. Chiu (2006). *E-Government Integration with Web Services and Alerts: A Case Study on an Emergency Route Advisory System in Hong Kong.* Proceedings of the 39th Hawaii International Conference on System Sciences. Kauai, Hawaii.

Dantas, A., Nicholson, A., Seville, E. (2005). *Information Sharing During Disaster: Can we do it better?* Resilient Organisations Programme, New Zealand.

Dantas, A., Seville, E., Gohil, D. (2007) Information Sharing During Emergency Response and Recovery: A Framework for Roading Organisations; Journal of the Transportation Research Board, Vol 2022, pp. 21-28; ISSN 0361-1981.

DeBlasio A. J., Zamora A, Mottley F., Brodesky R., Zirker M. E., Crowder M., (2002). Effects Of Catastrophic Events On Transportation System Management And Operations Northridge Earthquake, January 17, 1994. U.S. Department of Transportation report. Prepared by U.S. Department of Transportation Research and Special Programs Administration Volpe National Transportation Systems Center.

Earth and Space Sciences (2008). *The December 26, 2004 Sumatran Tsunami.* "http://www.ess.washington.edu/tsunami/Sumatra.htm". University of Washington. Last accessed 10 January 2008.

ESRI (2006). *GIS and Emergency Management in Indian Ocean Earthquake/Tsunami Disaster.* ESRI ® White Paper • May 2006. www.esri.com

Ferreira, F. Dantas, A. Seville, E. (2007). *Conceptual Dynamic Response Recovery Tool for Emergency Events.* Third International Forum on Engineering Decision Making (IFED): "Optimal strategies for disaster and hazard mitigation". 12th to 15th December 2007. Port Stephens, NSW, Australia.

Fredholm, L. (1999). *Emergency Management as Co-ordinated Cognitive Modelling on Different Time-scales.* Department of Fire Engineering, Lund University, Sweden. Report 311. ISSN: 1402-3504

Fu, L. Sun, D. Rilett, L. R. (2006). *Heuristic shortest path algorithms for transportation applications: state of the art.* Computers and Operations Research, Volume 33, Issue 11 (p. 3324-3343). ISSN.: 0305-0548. Elsevier Science Ltd.

Giarratano, J. Riley, G. (1998). *Expert Systems: Principles and Programming.* PWS Publishing Company, United States of America, Boston, MA. ISBN 0-534-95053-1.

Huyck C., Chung H. C., Cho S., Mio M., Ghosh S., Eguchi R., & Mehrotra S. (2006). Loss estimation online using INLET (Inter-based Loss Estimation Tool). Proceedings of the 8th U.S. National Conference on Earthquake Engineering, San Francisco. Paper No. 1535.

Kawata, Y *et al.* (2005) Comprehensive analysis of the damage and its impact on coastal zones by the 2004 Indian Ocean tsunami disaster. Disaster Control Research Center. Tohuko University, Japan. http://www.tsunami.civil.tohoku.ac.jp. Last accessed 23 January 2008.

Li, H. Bliemer, M. C. J. Bovy, P. H. L. (2007). *Network Reliability-Based Optimal Toll Design.* Proceedings of the INSTR 2007 Symposium (H. J. van Zuylen eds.). Holand, The Hague. 19th and 20th of July 2007.

Liu, H. X. Ban, J. X. Ma, W. Mirchandani, P. B. (2006 a). *Model Reference Adaptive Control Framework for Real Time Traffic Management under Emergency Evacuation.* Proceedings of the 85th Annual Meeting of the Transportation Research Board (CD-ROM), Washington.

Liu, Y. Lai, X. Chang, G. (2006 b). *A Cell-Based Network Optimization Model For Staged Evacuation Planning Under Emergencies.* Proceedings of the 85th Annual Meeting of the Transportation Research Board (CD-ROM), Washington, D.C.

Mendonca, D. *et al.* (2006). *Designing Gaming Simulations for the Assessment of Group Decision Support Systems in Emergency Response.* Safety Science. Published by Elsevier Ltd. Safety 1407, 13 January 2006.

Menthora S., Butts. C., Kalashnikov D., Venkatasubramanian N., Rao R., Chockalingam G., Eguchi R., Adams, B. Huyck C. (2004). *Project Rescue: Challenges in Responding to the Unexpected*. Invited Paper in SPIE - The International Society for Optical Engineering. Vol. 5304, pp.179-192.

Nagae, T. Akamatsu, T. (2007). *An Efficient Algorithm for a Maximum Routing Model for Hazards Materials*. Proceedings of the INSTR 2007 Symposium (H. J. van Zuylen eds.). Holand, The Hague. 19th and 20th of July 2007.

New Zealand (2002). Civil Defence Emergency Management Act 2002.

Nicholson, A. (2007). *Optimizing Network Terminal Reliability*. Proceedings of the INSTR 2007 Symposium (H. J. van Zuylen eds.). Holand, The Hague. 19th and 20th of July 2007.

Pomykalski, J. J. Truszkowski, W. F. Brown, D. E. (1999). *Expert System*. Wiley Encyclopedia for Electrical and Electronics Engineering. February 1999. Editor: J. Webster.

Power, D. J. (2005). *Decision Support Systems: Frequently Asked Questions*. iUniverse Inc. ISBN: 0-595-33971-9. United States of America

Russian Institute of Computational Mathematics and Mathematical Geophysics (2008). *Tsunami Laboratory*. "http://tsun.sscc.ru/tsulab/20041226fat.htm". Last accessed 10 January 2008.

Siler, W. Buckley, J.J. (2004). *Fuzzy Expert Systems and Fuzzy Reasoning*. ISBN: 978-0-471-38859-3.

Takeuchi, T. Kondo, A. (2003). *Allocation Analysis for 'Earthquake Tsunami Refuge Facilities' by Maximizing Successful Passage*. The 8th International Conference on Computers in Urban Planning and Urban Management Conference. Tohoku University, Sendai.

Vedder, R. G. (1990). *Expert Systems for Crisis Management: The HIT Project*. Book: Expert Systems for Business and Management. Edited by Jay Liebowitz. Prentice-Hall Inc. ISBN 0-13-296468-6ù

Werner S. D., Lavoie J.P., Eitzel C., Cho S., Huyck C., Ghosh S., Eguchi R. T., Taylor C. E. & Moore J. E. (2004). *REDARS 1: Demonstration Software for Seismic Risk Analysis of Highway Systems.* Multidisciplinary Centre for Earthquake Engineering MCEER Research Progress and Accomplishments Report 2001-2003. Pp. 17-34.

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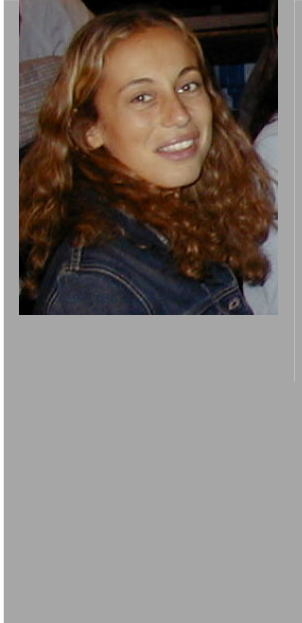
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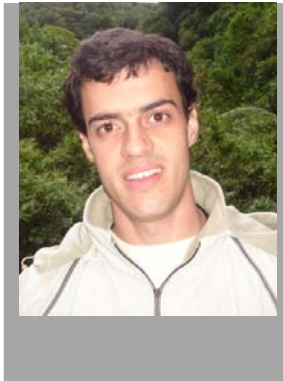
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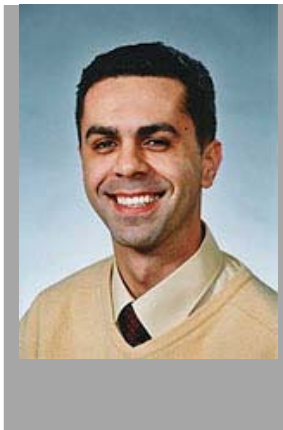
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