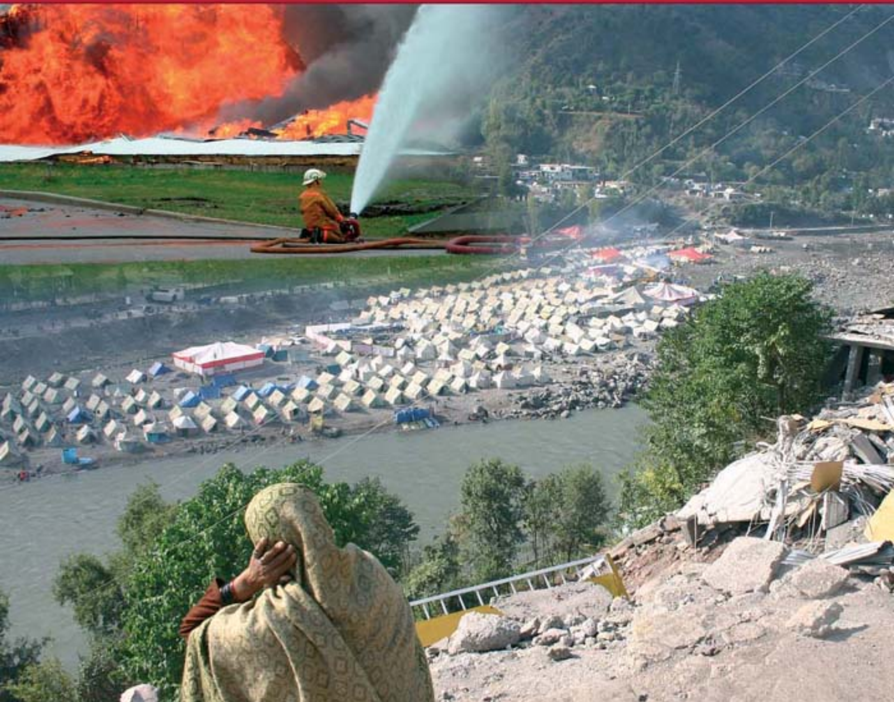
Disaster Management and Human Health Risk II

Reducing Risk, Improving Outcomes



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DISASTER MANAGEMENT AND HUMAN HEALTH: REDUCING RISK,
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Disaster Management II

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Published by

WIT Press
Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK
Tel: 44 (0) 238 029 3223; Fax: 44 (0) 238 029 2853
E-Mail: witpress@witpress.com
http://www.witpress.com

For USA, Canada and Mexico

Computational Mechanics Inc
25 Bridge Street, Billerica, MA 01821, USA
Tel: 978 667 5841; Fax: 978 667 7582
E-Mail: infousa@witpress.com
http://www.witpress.com

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available
from the British Library

ISBN: 978-1-84564-536-6
ISSN: 1746-4498 (print)
ISSN: 1743-3509 (online)

The texts of the papers in this volume were set individually by the authors or under their supervision. Only minor corrections to the text may have been carried out by the publisher.

Printed in Great Britain by MPG Books Group, Bodmin and King's Lynn.

Preface

The second International Conference on Disaster Management was reconvened in 2011 in Orlando, Florida following the success of the first meeting held at the Wessex Institute of Technology in the New Forest, UK. Florida is no stranger to the increasing number of natural disasters affecting millions of people around the world, having periodically suffered the ravages of hurricanes, with a recent disastrous sequence of four hurricanes delivering devastating blows to the State from both Gulf and Atlantic coasts in 2004. Most recently, Florida's economy was seriously affected by the Deep Horizon oil spill in the Gulf of Mexico in spite of its coastline being mostly spared from any major damages.

The Conference attracted outstanding contributions from researchers throughout the world. The collected works, published in this book, reflect the excellent work of all contributing authors and the care taken by the Scientific Advisory Committee and other colleagues in reviewing the presentations.

The modern world faces a wide spectrum of threats from human-made disasters that can be attributed to the failure of strained and antiquated industrial and energy installations as well as the deliberate sabotage from terrorists and vandalism during violent political upheavals. Added to this is the ever present threat from natural causes ranging from biological pandemics to earthquakes and Tsunamis.

The most recent tragic event is the Sendai 9.0 magnitude earthquake and the ensuing Tsunami that struck Japan resulting in devastating loss of life and property. Thousands of people lost their lives in one state alone with the numbers soaring as of the writing of this preface. Characterized as Japan's most severe crisis since WWII, this disaster is compounded with the threat of major failures and explosions at Japan's nuclear facilities. It is to the victims of the Sendai disaster and to the Japanese people that we dedicate this conference.

The Editos
Orlando, USA, 2011

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Section 1
Disaster analysis, monitoring and mitigation

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Tsunami risk mapping simulation for Malaysia

S. Y. Teh[1], H. L. Koh[2], Y. T. Moh[1], D. L. DeAngelis[3,4] & J. Jiang[4]
[1]*School of Mathematical Sciences, Universiti Sains Malaysia, Malaysia*
[2]*Disaster Research Nexus, School of Civil Engineering, Universiti Sains Malaysia, Malaysia*
[3]*U.S. Geological Survey, Gainesville, Florida, USA*
[4]*Department of Biology, University of Miami, Florida, USA*

Abstract

The 26 December 2004 Andaman mega tsunami killed about a quarter of a million people worldwide. Since then several significant tsunamis have recurred in this region, including the most recent 25 October 2010 Mentawai tsunami. These tsunamis grimly remind us of the devastating destruction that a tsunami might inflict on the affected coastal communities. There is evidence that tsunamis of similar or higher magnitudes might occur again in the near future in this region. Of particular concern to Malaysia are tsunamigenic earthquakes occurring along the northern part of the Sunda Trench. Further, the Manila Trench in the South China Sea has been identified as another source of potential tsunamigenic earthquakes that might trigger large tsunamis. To protect coastal communities that might be affected by future tsunamis, an effective early warning system must be properly installed and maintained to provide adequate time for residents to be evacuated from risk zones. Affected communities must be prepared and educated in advance regarding tsunami risk zones, evacuation routes as well as an effective evacuation procedure that must be taken during a tsunami occurrence. For these purposes, tsunami risk zones must be identified and classified according to the levels of risk simulated. This paper presents an analysis of tsunami simulations for the South China Sea and the Andaman Sea for the purpose of developing a tsunami risk zone classification map for Malaysia based upon simulated maximum wave heights.

Keywords: tsunami risk simulation, early warning system.

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110011

1 Introduction

Tsunami can be a devastating natural disaster that could inflict great destruction to affected coastal communities. Therefore, proper management systems, including tsunami risk maps, should be developed to address the impact of tsunami. The death toll caused by the 2004 Andaman tsunami is around 250,000 people. Public education, total risk management and coastal zone planning to reduce tsunami hazard were non-existent in the region, resulting in this high death toll. After the 2004 Andaman tsunami, many countries have been working independently and collectively to develop early tsunami warning systems for the affected countries. To provide improved protection against future tsunami, the Ministry of Science Technology and Innovation (MOSTI) of Malaysia established the Malaysian National Tsunami Early Warning System (MNTEWS) at the Malaysian Meteorological Department (MMD) to provide early warning on tsunami generated in the Andaman Sea and the South China Sea that might affect Malaysia. The main objective of MNTEWS is to detect earthquake events that might result in a destructive tsunami and to disseminate accurate and timely warnings so that appropriate actions can be taken. The MNTEWS consists of three components namely: (1) Data and information collection, (2) Data processing and analysis, and (3) Dissemination of early warning regarding tsunami. A network of 14 seismic stations is installed in Malaysia, six in Peninsular Malaysia, five in Sabah and three in Sarawak, for real-time monitoring of earthquake occurrences in the region [1]. To complement the Malaysian network, MMD also receives real-time seismic data from eight seismic stations in Indonesia through VSAT and from 26 seismic stations from other countries through internet. A total of 6 tide gauge stations have been installed at six selected risk areas, with three over the north-western part of Peninsular Malaysia, one in the northeast region of Peninsular Malaysia and two in Sabah, to measure and monitor wave conditions and water elevations along the shores of Malaysia. Three deep ocean buoys are deployed at strategic locations to facilitate early detection of tsunamis. As an integral component of MNTEWS, tsunami risk maps for Malaysia are developed based upon simulations of TUNA to provide critical information regarding areas subject to high risk. This paper briefly presents the risk map and issues related to its development.

2 TUNA: Tsunami Utilities and Application

After the 2004 tsunami, a research team in USM immediately initiated a tsunami research program by developing an in-house tsunami simulation model named TUNA. TUNA model simulations enable a better understanding of the mechanism of tsunami generation, propagation and runup. Simulated propagation wave heights from TUNA compare well with results obtained from a well-established model COMCOT [2]. Simulated runup heights also agree generally with measured runup heights of the 2004 tsunami along the northwest coast of Peninsular Malaysia [3]. The model TUNA has since been enhanced to allow the assessment of the role of mangrove for coastal protection [4]. The impact of storm surges induced by tsunami or wind-waves on coastal vegetation has also been investigated [5, 6]. The propagation of tsunami in deep oceans may be simulated by the depth-averaged two-dimensional shallow water equations (SWE), following the proposal of the Intergovernmental Oceanography Commission (IOC). The SWE is applicable when the wave heights are much smaller than the depths of water, which in turn are much smaller than the wavelengths. These conditions are fulfilled for tsunami propagations in the Andaman Sea and the South China Sea. Hence, under normal assumptions typically applicable to tsunami propagations in the deep ocean, the hydrodynamic equations describing the conservation of mass and momentum can be depth averaged [7, 8] and may be written as eqns (1) to (3). Here, discharge fluxes (M, N) in the x- and y- directions are related to velocities u and v by the expressions $M = u\,(h + \eta) = uD$, $N = v\,(h + \eta) = vD$, where h is the sea depth and η is the water elevation above mean sea level. The numerical approximations of these three equations are available in Koh et al. [3]. Tsunami simulations for the South China Sea are presented next.

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \tag{1}$$

$$\begin{aligned} &\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} \\ &+ \frac{gn^2}{D^{7/3}} M\sqrt{M^2 + N^2} = 0 \end{aligned} \tag{2}$$

$$\begin{aligned} &\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} \\ &+ \frac{gn^2}{D^{7/3}} N\sqrt{M^2 + N^2} = 0 \end{aligned} \tag{3}$$

3 Tsunami simulations in the south China sea

The USGS has issued a report strongly suggesting the potential risk of tsunami along the entire Pacific subduction zones [9]. It identified the Manila Trench as a high risk tsunamigenic earthquake zone, where the Eurasian plate actively subducts eastward underneath the Luzon volcanic arc on the Philippine Sea plate. This subduction zone can rupture and generate large tsunamis that will have devastating impacts on the affected countries. In the South China Sea (SCS) region, few studies on tsunami threat have been conducted in the past. Based on historical tsunamigenic record for the region, it is believed that potential tsunami sources exist in the region due to the Manila subduction zone seismic activities [10–12]. Various hypothetical earthquake-ruptured faults have been reported for the Manila subduction zone [9, 10, 13, 14]. The tsunami source considered in this paper is generated by a giant earthquake of magnitude M_w above 9, which is considered as the worst case scenario by Megawati et al. [15]. The adopted fault parameters are derived from studies conducted by Bautista et al. [16] and Wu et al. [17]. The earthquake-ruptured fault consists of a series of 33 segments, each with its own orientation, size and slip magnitude. The initial water surface deformation simulated for the simultaneous rupture of all 33 segments is illustrated in fig. 1 (left). A total of 17 observation points located offshore at depths of about 50 m are placed near the coasts of the countries fringing the South China Sea to record the TUNA-simulated wave heights and arrival times.

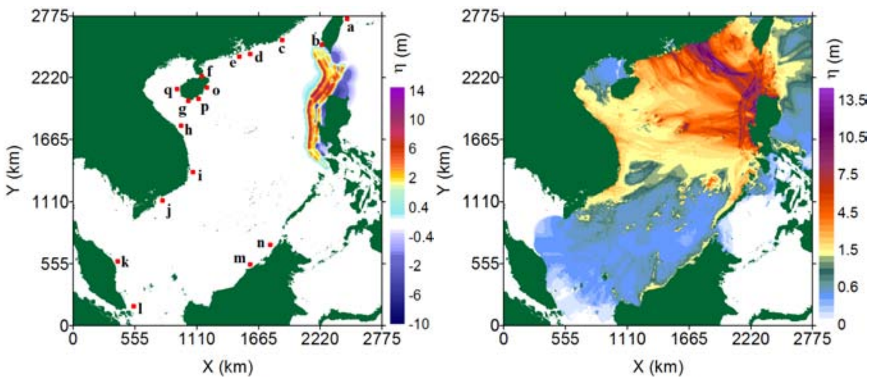

Figure 1: Initial sea surface deformation with observation points (left) and maximum elevation during the first 11 hours of propagation (right) simulated by TUNA.

The simulated maximum wave heights are presented in fig. 1 (right), with higher wave heights recorded along the main propagation axis of the source. Certain locations along the coasts of Philippines, Taiwan, China, and Vietnam receive significant waves. These locations are situated near the tsunami source and directly along the propagation path of the tsunami. On the other hand, countries which are located far away from the Manila Trench receive low tsunami waves. These countries include Peninsular Malaysia and Singapore. Simulated snapshots of the tsunami waves propagating across the South China Sea at various time intervals are shown in fig. 2. The top-left frame in fig. 2 indicates that the waves reach the southern coast of Taiwan in about half an hour. The top-right frame shows the waves heading towards the coasts of China and Vietnam. The bottom-left frame indicates that the waves reach the coasts of China and Vietnam about 2.5 hours after the earthquake. Eight hours after the earthquake, the tsunami waves have passed by the coasts of Sabah and Sarawak, continuing to propagate towards Peninsular Malaysia and Singapore (fig. 2, bottom right).

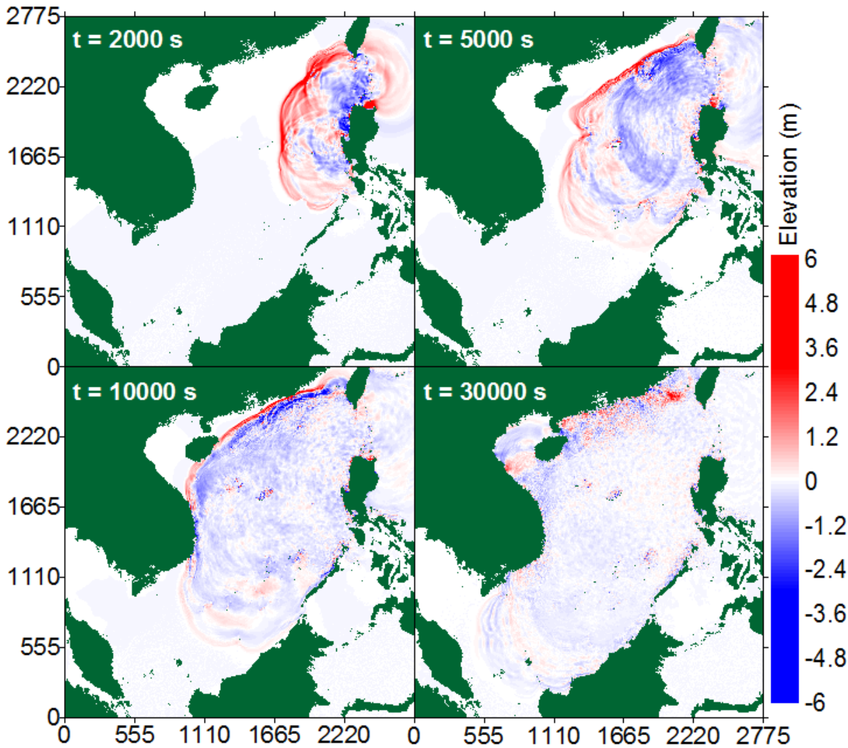

Figure 2: Snapshots of tsunami propagation simulated by TUNA.

Table 1 summarizes the arrival times and the simulated maximum wave heights at the 17 observation points, located offshore at depth of about 50 m. The time series at six chosen observation points are presented in fig. 3. These six locations are Kaoshiung, Sanya, Hong Kong, Da Nang, Miri and Terengganu. The first waves arrive in Kaoshiung after 0.3 hour with maximum offshore height of 1.8 m. Sanya receives maximum waves of 1.5 m three hours after the earthquake. The tsunami waves arrive offshore of Hong Kong at about 2.6 hours with maximum offshore wave heights of 5.5 m. Da Nang receives maximum offshore wave height of 2 m after 2.8 hours. The waves arrive offshore of Miri after 2.8 hours with maximum height of 0.3 m. The waves finally reach Terengganu after 9 hours with maximum offshore wave heights of 0.2 m. Simulated wave height at offshore of depth 50 m might be amplified by an average factor of 2 to 4 as the waves run up the shallow beaches [3, 18]. Accounting for runup amplification, tsunami wave heights along Malaysian coasts are not expected to exceed 1 m. Hence, tsunami risk maps for Malaysia due to tsunamis originating from the Manila Trench are not presented in this paper.

Table 1: Simulated wave elevation and arrival time of first wave peak at the observation points indicated in fig. 1 (left).

Location		Height (m)	Arrival time (h)	Location		Height (m)	Arrival time (h)
a	Hualien	1.0	1.0	j	Vungtau	0.5	5.0
b	Kaoshiung	1.8	0.3	k	Terengganu	0.2	9.4
c	Shantou	4.0	2.6	l	Singapore	0.1	10.4
d	Hong Kong	5.5	2.7	m	Miri	0.3	2.8
e	Macau	4.2	3.2	n	Kota Kinabalu	0.4	2.3
f	Haikou	0.8	4.8				
g	Sanya	1.5	3.0	o	Qionghai	1.4	2.3
h	Da Nang	2.0	2.8	p	Lingshui	1.3	2.2
i	Nhatrang	0.9	1.7	q	Dongfang	0.5	5.5

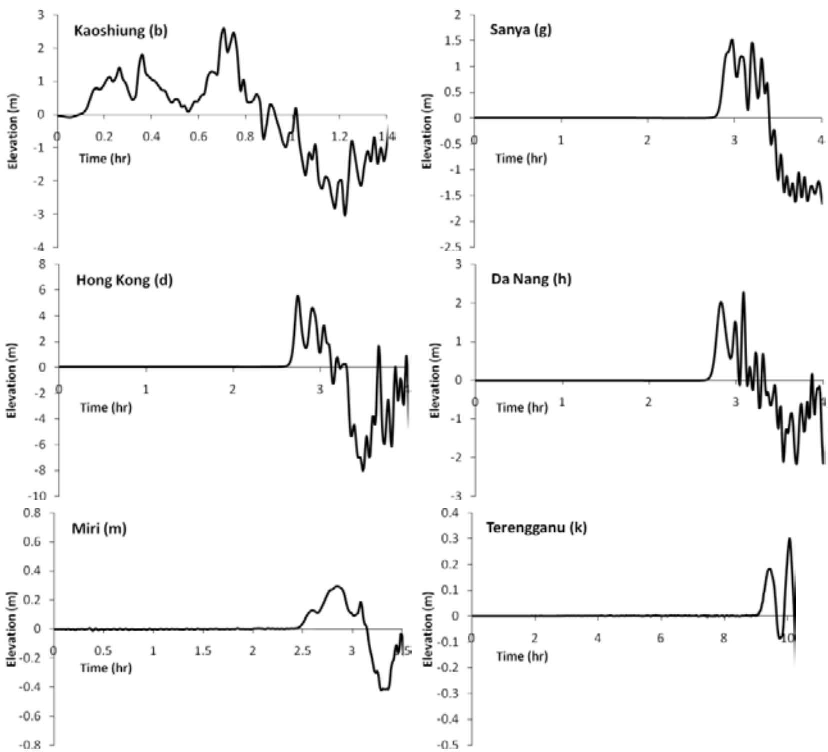

Figure 3: Simulated wave heights off shore at six of the observation points.

During the 2004 Andaman tsunami, beach runup waves measuring up to 4 m were reported and simulated for the northwest coast of Peninsular Malaysia [3]. Waves exceeding 3 m are considered as highly dangerous. A total of 68 people in Malaysia were killed by this 2004 tsunami. As part of the tsunami preparedness program, simulations are performed for tsunamis originating in the Andaman Sea to investigate the potential impact on the northwest coast of Peninsular Malaysia. These simulations are performed on the basis of several credible tsunami sources [19]. The scenarios of tsunami sources adopted in previous studies did not place Peninsular Malaysia directly on the propagation path of the tsunami. A concern raised is the potential impact of future tsunamis that might result in waves propagating directly towards northwest Peninsular Malaysia. This is currently considered the worst-case scenario, which is addressed in the following section.

4 Andaman tsunami risk map

For this worst-case scenario, we consider one single earthquake-ruptured fault of 600 km in length and 130 km in width. The fault is oriented in a manner so that the waves would propagate directly towards northwest Peninsular Malaysia. The remaining fault parameters used here are similar to those reported in Koh et al. [3]. Figure 4 shows the time series of the simulated wave heights at offshore locations with depth of 50 m at three selected points, namely Penang (A), Langkawi (B) and Phuket (C). The locations of A, B and C are indicated in fig. 5. Maximum offshore wave height of about 8 m is recorded at Phuket, arriving about 1.8 hours after the earthquake (fig. 4, right). Penang and Langkawi may be hit by offshore waves up to 2 m about three hours after the earthquake (fig. 4, left and middle). It should be noted the waves of 2 m offshore may be amplified to runup heights of 4–8 m along the beaches, based upon the mean amplification factors of 2 to 4. Hence, Penang and Langkawi might receive height up to 8 m along the beaches. The amplification factor depends on the topography and bathymetry at the coastal zones. The initial water displacement generated by this fault rupture is shown in fig. 5 (top left). Subsequent propagation of the tsunami waves is illustrated in a series of snapshots in fig. 5. Comparison between simulated maximum wave heights for this worst case scenario and the 2004 Andaman tsunami are illustrated in fig. 6. The orientation of the source in this worst case scenario directs the waves toward the coasts of northwest Peninsular Malaysia, leading to high wave heights along these coasts as compared to the 2004 tsunami.

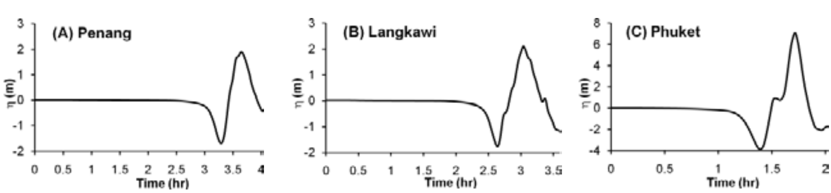

Figure 4: Simulated wave heights off shore near Penang, Langkawi and Phuket.

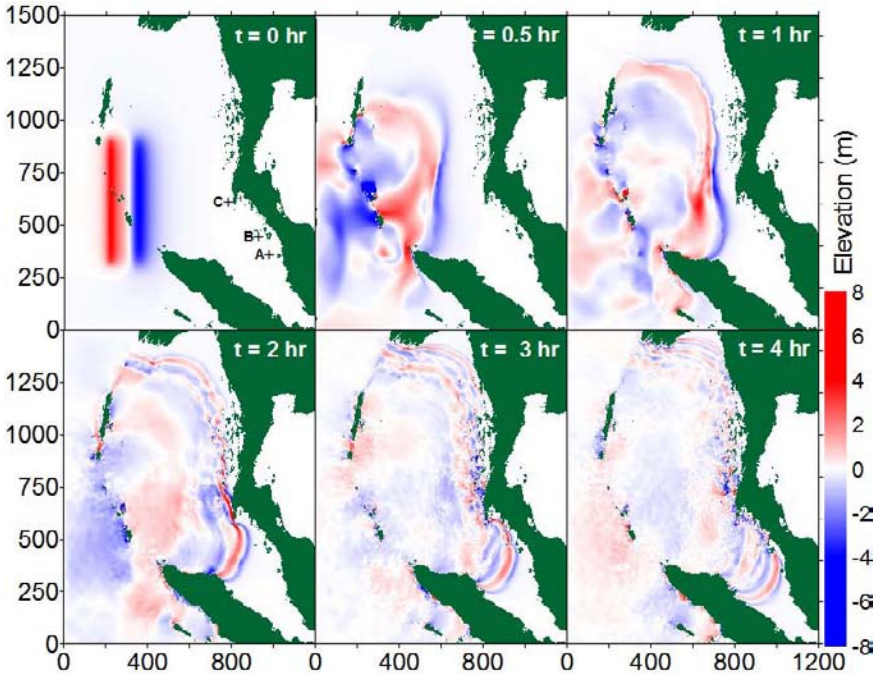

Figure 5: Snapshots of tsunami propagation generated by a source in the Andaman Sea.

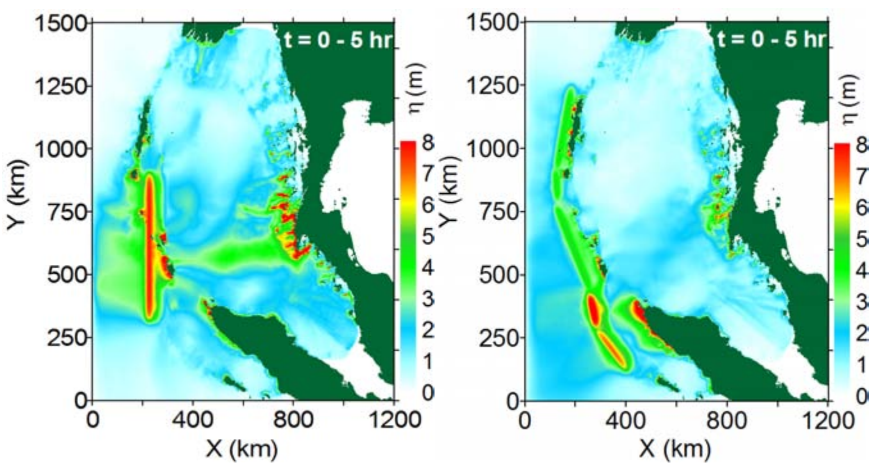

Figure 6: Simulated maximum wave heights during the first 5 hours for the worst case scenario (left) and the 2004 Andaman tsunami (right).

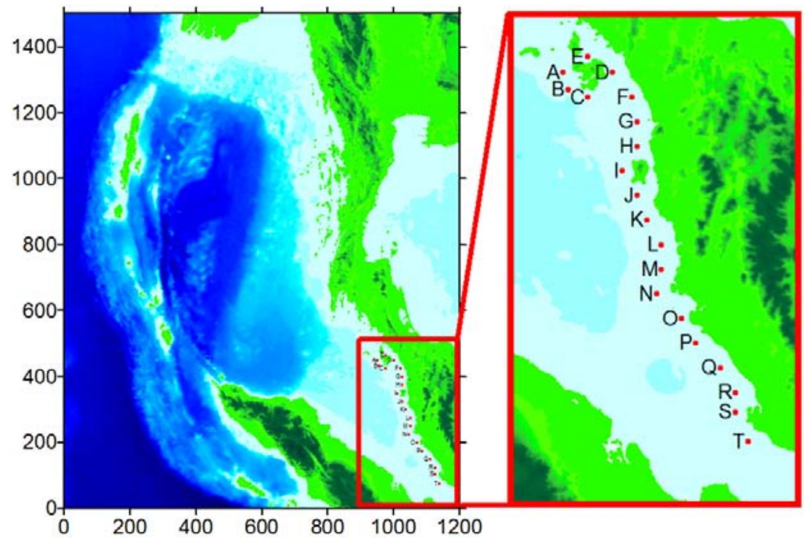

Figure 7: Bathymetry and observation points placed along northwest Peninsular Malaysia for tsunami hazard analysis.

Table 2: Simulated maximum wave heights for the worst case scenario at the twenty observation points shown in fig. 7.

Maximum Wave Height (m)									
A	B	C	D	E	F	G	H	I	J
1.8	1.9	2.4	0.8	0.9	4.6	2.6	1.8	2.6	2.4
K	L	M	N	O	P	Q	R	S	T
1.8	1.5	1.3	1.8	3.9	1.1	0.9	0.3	0.15	0.1

Table 3: Simulated arrival times for the worst case scenario at the twenty observation points shown in fig. 7.

Arrival time (hr)									
A	B	C	D	E	F	G	H	I	J
3.25	3.35	3.57	4.54	3.73	4.75	4.44	4.32	4.27	4.45
K	L	M	N	O	P	Q	R	S	T
4.65	4.94	5.00	5.12	6.07	6.3	6.72	7.11	7.18	7.53

For the purpose of communicating tsunami risks to local communities and local authorities, tsunami risk maps are developed. The tsunami hotspots identified are located in northwest Peninsular Malaysia as shown in fig. 7. Twenty observation points are placed along the hotspots to record the maximum simulated wave heights. Tables 2 and 3 show respectively the maximum offshore

Table 4: Tsunami index ranking system adopted for northwest coast of Peninsular Malaysia.

Variables	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Maximum Tsunami Height	< 0.5 m	0.5 – 1.0 m	1.0 – 2.0 m	2.0 – 3.0 m	> 3.0 m

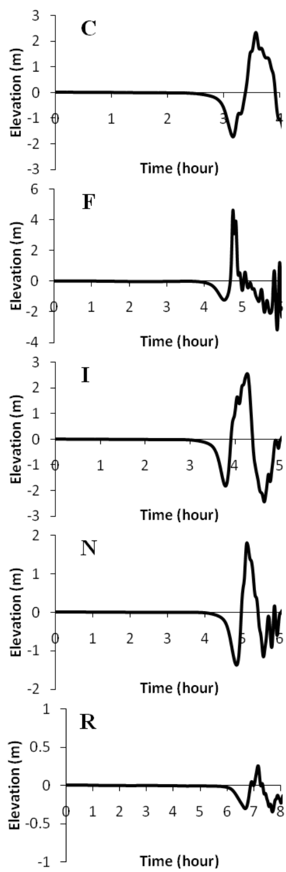

Figure 8: Time series of the simulated wave heights at Langkawi (C), Kuala Kedah (F) Penang (I), Pangkor island (N) and Kuala Selangor (R).

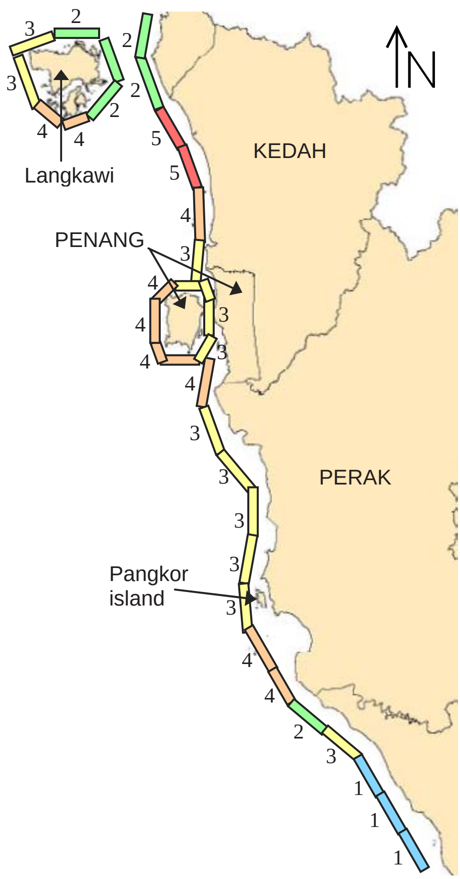

Figure 9: Tsunami hazard map using the index ranking system in table 4. The numbers indicate tsunami risk along the coast under the worst case scenario (1 – very low; 2 – low; 3 – moderate; 4 – high; 5 – very high).

wave heights and arrival times at the 20 observation points. These simulated wave heights are then used to develop the tsunami risk map following the tsunami index ranking system shown in table 4, based upon maximum wave heights at offshore locations with depth of 50 m. Time series of simulated tsunami waves at selected locations namely Langkawi, Kuala Kedah, Penang, Pangkor island and Kuala Selangor are shown in fig. 8. Based upon this worst case scenario, the tsunami risk map developed is shown in fig. 9.

5 Conclusion

This paper has presented tsunami simulation results for two mega tsunamis originating from the South China Sea and the Andaman Sea. Tsunami risk map is presented for the worst-case tsunami due to submarine earthquake in the Andaman Sea.

Acknowledgements

Financial support provided by Grants 1001/PMATHS/817024, 1001/PMATHS/817025 and 1001/PMATHS/811093 is gratefully acknowledged.

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Physical vulnerability of critical facilities in Grand Cayman, Cayman Islands

D. A. Novelo-Casanova & G. Suárez
Instituto de Geofísica, Universidad Nacional Autónoma de México, México

Abstract

Using the methodology developed by the North Carolina Department of Environment and Natural Resources, USA, we determined the physical vulnerability to the impact of hazards of the main critical facilities at Grand Cayman (*GC*), Cayman Islands. Our results indicate that: 1) About 82% of the emergency response infrastructure, 95% of the government facilities, and 85% of the utilities have physical vulnerabilities in the range from low to moderate; 2) Only 12% of all identified critical facilities at *GC* are exposed to natural and man-made hazards with a high vulnerability; 3) *GC* shows a very good level of protection of its critical facilities to natural hazards; 4) Explosions or leaks of the Airport Texaco Fuel Depot and the fuel pipeline, could impact the George Town Red Cross Building, the Caribbean Utilities and the Owen Roberts International Airport. An explosion of the Home Gas Terminal could damage the John Gray High School, which is also used as shelter in case of emergencies.
Keywords: vulnerability, hazards, physical vulnerability, natural hazards, man-made hazards, critical facilities, Grand Cayman, Cayman Islands.

1 Introduction

Based on the characteristics of the main hazards that may affect the Cayman Islands (*CI*) [1], we identified the level of physical vulnerability for each of the 48 main critical facilities in Grand Cayman (*GC*). The main objectives of the assessment performed in this work are: 1) To prepare maps with critical facilities that might be exposed to or threatened by the natural or man-made hazards identified in *GC*, and 2) To increase the overall awareness of decision makers for disasters prevention and mitigation actions at *CI*.

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110021

It is important to underline that a full vulnerability analysis of the islands should include a complete and quantitative vulnerability assessment of the physical, structural, organizational, historical, socio-economic, and environmental parameters that control the exposure to natural and man-made hazards. To this end, this work constitutes the basis of a future, quantitative vulnerability assessment.

The data for this study were collected via electronic means and from scientific sources in the public domain, including data generated by the Lands and Surveys Department of the *CI*. The Hazard Management Cayman Islands (*HMCI*) provided part of this information. We interpreted and manage the source data with the use of documentary sources such as the list of institutions and facilities reported on the map of Hurricane Ivan Preliminary Damage Assessment [2] and the facilities reported on the Grand Cayman's Public Safety Map.

2 The Cayman Islands

Located in the western Caribbean Sea to the northwest of Jamaica, *CI* is a British overseas territory comprised of three islands: *GC*, Cayman Brac (*CB*), and Little Cayman (*LC*), fig. 1. These three islands occupy around 250 km^2 of land area [3]. *GC* is approximately 35 km long and 13 km at the widest point wide. The highest elevation is about 18 m above sea level and the most striking geographical feature is the North Sound, a shallow reef protected lagoon with an area of about 56 km^2. *CB* lies about 145 km northeast of *GC*. It is about 19 km long and a little over 1.6 km wide. *LC* is 8 km west of *CB* and is 16 km long and 3 km at its widest point, fig. 1. It is the flattest of the three islands with its highest elevation being 12 m. To the west, an 11 km channel separates *CB* from *LC* [3]. The three islands are mostly flat and were formed by large coral heads, covering submerged ice age peaks of western extensions of the Cuban Sierra Maestra range. The highest point is The Bluff, a limestone outcrop 43 m in height on the eastern end of eastern *CB*. The *CI's* lowest elevation is the Caribbean Sea at sea level [3]. Due to the porous nature of the limestone rocks that are present along with the absence of much relief of any kind, all of the Caymans lack rivers or streams [4].

The islands are located above the Cayman Trough (*CT*) which is a depression area on the seafloor of the Caribbean that extends from the Belize margin to northern Jamaica, fig. 1. At its deepest point, the *CT* is over 7500 m deep [5]. This margin consists of a 100-250 km wide seismogenic zone of generally left-lateral, strike-slip deformation which covers over 2000 km along the northern edge of the Caribbean Sea. This left-lateral strike-slip displacement is due to the eastward movement of the Caribbean plate relative to the adjacent North American plate [5]. Geological and geophysical data from the region suggest that the *CT* is underlain by oceanic crust accreted along a short north-south spreading center located between the Oriente and Swan transform faults [6].

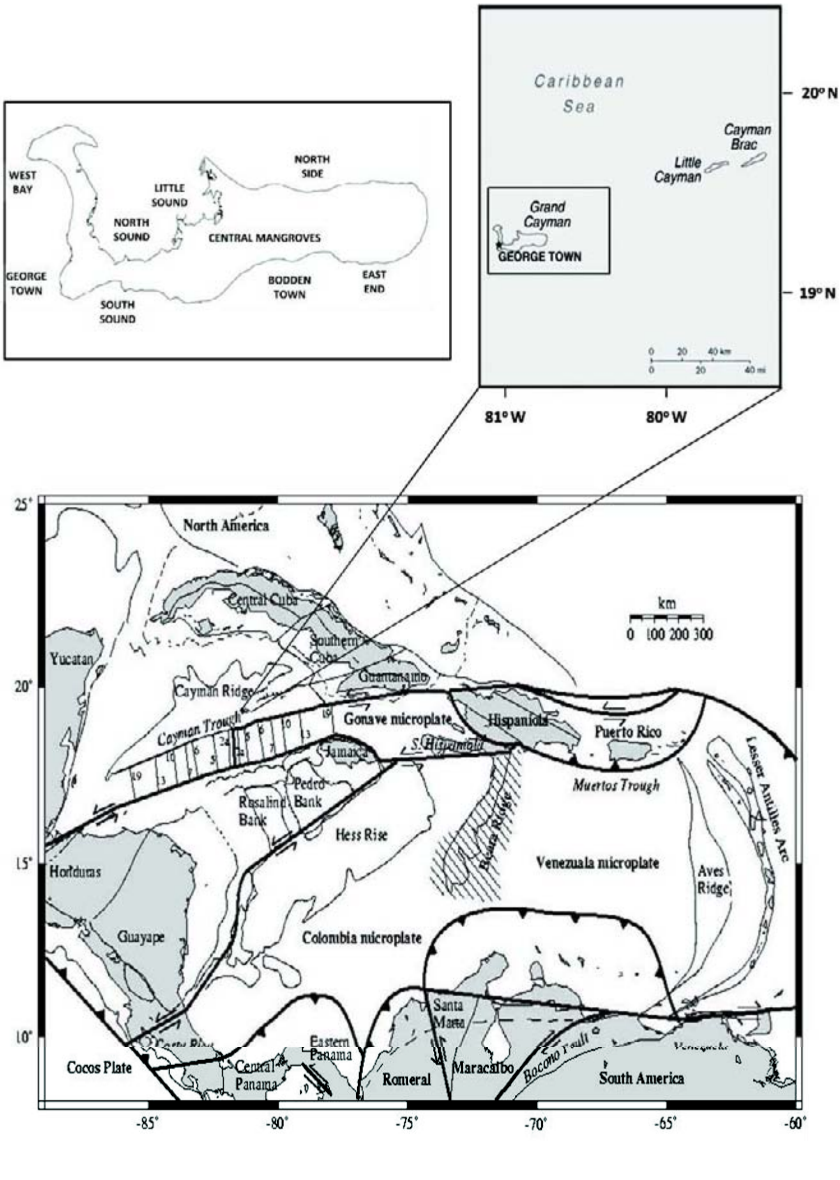

Figure 1: The tectonic boundaries of the Caribbean Plate and the location of the Cayman Islands. The major geologic faults in the northern Caribbean are shown. The Gonave plate is bounded by the Oriente fault to the north, that passes just south of the Cayman Islands, and the Walton fault to the south of it, passing through Jamaica [1].

3 Natural and man-made hazards in the Cayman Islands

Novelo-Casanova and Suárez [1] analyzed the various natural and man-made hazards that may affect *CI* and determined the level of exposure of *GC* to these events. The magnitude, frequency, and probability of occurrence of the natural and man-made hazards that may potentially affect the islands were identified and ranked. The results of Novelo-Casanova and Suárez [1] indicate that the more important natural hazard to which the *CI* is exposed is clearly hurricanes. To a lesser degree, the islands may be occasionally exposed to earthquakes and tsunamis. Explosions or leaks of the Airport Texaco Fuel Depot and the fuel pipeline at *GC* are the most significant man-made hazards.

The results of the hazard evaluation of Novelo-Casanova and Suárez [1] indicate that there are four areas in Grand Cayman with various levels of exposure to natural and man-made hazards: The North Sound, Little Sound and Eastern West Bay (Area 1) show a very high level of exposure; The Central Mangroves, Central Bodden Town, Central George Town and the West Bay (Area 2) have high level of exposure; The Northwestern West Bay, Western Georgetown-Bodden Town, and East End-North Side (Area 3) are under moderate levels of exposure. The remainder of the island shows low exposure (Area 4).

4 Methodology

For our research, we adapted the methodology developed by the North Carolina Department of Environment and Natural Resources and other research partners during the study entitled "New Hanover County/Wilmington Project Impact Partnership" [8]. Briefly, the steps involved in this methodology are as follows:

1. Hazard Identification
2. Hazard Analysis
3. Critical Facility Analysis
4. Societal Analysis
5. Economic Analysis
6. Environmental Analysis
7. Mitigation Opportunity Analysis

Novelo-Casanova and Suárez [1] evaluated the level of exposure to natural and man-made hazards of the *CI*, considering the first two steps. In step 1, hazards are characterized by its probability of occurrence, size of area of impact and the potential damage. For each identified main hazard, a total score is obtained following eqn. (1) by assigning weights to each factor depending on how critical that factor is:

Total Score=(Frequency+Area of Impact) x Potential Damage Magnitude (1)

The frequency, area of impact, and potential damage magnitude values are defined by a scale of numbers ranging from 1 to 6, where: extremely low= 1 and very high= 6. The purpose in this step is to identify the hazards and their potential impacts. It is a subjective exercise where the total scores alone do not have absolute statistical significance. The comparison of scores, however, will provide relative rankings that guide the vulnerability assessment process as well as the establishment of hazard mitigation priorities.

In step 2, the exposure areas are determined for each hazard. The objective of this step is to target priority areas for which a hazard evaluation is needed. The purpose is to identify geographically the areas that are most likely to be affected by a given hazard. Once the exposed areas are identified, a prioritization is developed using local data sources. For each identified area a relative level of exposure to the specific hazard being addressed is established.

To determine the level of exposure to natural and man-made hazards of critical facilities at *CI*, we considered the procedures of step 3. In step 3, the vulnerability of key individual facilities or resources within the community is assessed. Because it is not usually feasible to conduct such an analysis for every structure in a community, the work is focused on identifying the categories of structures that are considered "critical facilities" for purposes of conducting individual facility assessments. Next, a critical facilities database is established by collecting some general information. The kind and amount of information collected depends on the intended use of the database. At a minimum, the database should contain information identifying facility types and locations. To help prioritize potential impact on the critical facilities, vulnerability scores for each of the critical facilities are established. Then, the score of each critical facility with the score of the hazard in each area is considered.

Here, using the relative priority scoring system developed by Novelo-Casanova and Suárez [1] for different areas at *GC*, fig. 2, an individual physical assessment for each critical facility at *CI* was conducted. This assessment was performed addressing the location of the facility relative to the potential exposure to the impacts of hazards of the area which the facility is located [1].

5 Inventory of critical facilities

For the purposes of the present work a critical facility is defined as: “A facility that is vital for the *CI*‘s ability to provide essential services and protect life and property and/or the loss of which would have a severe economic or catastrophic impact”. We considered the following three categories of critical facilities: Emergency Response, Government, and Utilities. Within the Emergency Response Facilities we considered Hospitals and Clinics, Police and Fire Stations and the National Emergency Operation Center. This infrastructure is crucial in any disastrous event to attend casualties. Within the Government Facilities we included government buildings, shelters, port and airport. Several schools in *GC* are also used as shelters in case of emergencies. These critical facilities are essential for the procurement of needed food and medical supplies during emergencies. In the Utilities category we considered fuel, water, and power resources that support the economy of the islands.

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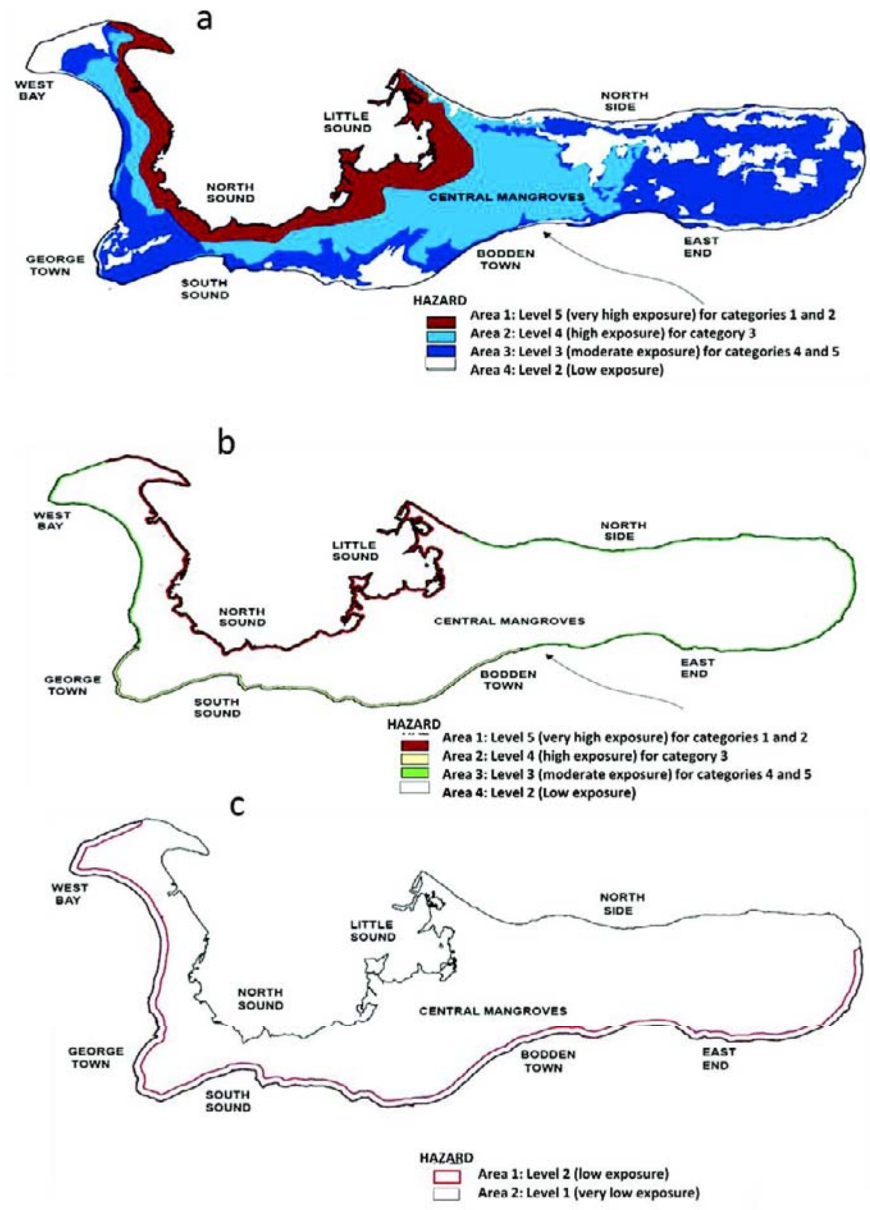

Figure 2: Flood (a) and storm surge areas (b) for different hurricane categories. The arrow indicates the direction of approach of the hurricane; (c) Tsunami hazard areas for tsunamis coming from the Caribbean Sea [1].

A total of 48 critical facilities were identified in our inventory. The George Town Red Cross Building was considered in both, the Emergency Response and Government facilities categories because this facility is also a shelter in case of emergencies.

6 Physical vulnerability of critical facilities

Following the methodology described above, for each critical facility within the three categories considered, we conducted an assessment addressing the location of the facility relative to the four identified hazard areas with different levels of exposure to the impact of hurricanes, earthquakes, tsunamis and man-made hazards, fig. 2 [1]. The physical vulnerability of critical facilities was evaluated using the ArcGIS software. Critical facilities were converted from a simple database of names and locations into a map "layer" of resources. This layer was combined with, or "overlaid" with the map layers of fig 2. This overlay was then used to identify the critical facilities that may be threatened by different hazard events ranked with a specific score, table 1.

Table 1: Level of hazards for different areas at Grand Cayman [1].

Hazard	Hazard Area	Hazard score
Hurricane		
Flooding (Fig 2a) and Storm surge (Fig 2b)		
Category 1 and 2	1	5
Category 3	2	4
Category 4 and 5	3	3
Remainder of Grand Cayman Island	4	2
Earthquake		
Entire Grand Cayman Island	1 to 4	1
Tsunami (Fig. 2c)		
Very Low	near to ocean	1
Remainder of Grand Cayman Island	4	0
Man-made hazard		
Fuel and gas tanks	Adjacent areas	1
Fuel pipeline	Adjacent areas	1
Remainder of Grand Cayman Island		0

Based on the total hazard score of the facility obtained from the sum of the individual score hazard to which the facility is exposed, we established the level of physical vulnerability for each critical facility considering the following thresholds:

- *Low Vulnerability*: total hazard score between 5 and 6. Low exposure to any of the identified main hazards at *CI*.
- *Moderate Vulnerability*: total hazard score between 7 and 8. Moderate exposure to at least floods and storm surges. The facility is located in a zone that is impacted by hurricane categories 4 and 5 that take place approximately every 100 years [1].
- *High Vulnerability*: total hazard score between 9 and 10. High exposure to at least floods and storm surges and to a lesser degree to tsunamis. The facility is located in an area exposed to hurricanes of category 3 (and above) that hit the islands once every 9.06 years [1].
- *Very High Vulnerability*: total hazard score of 11 or greater. Very high exposure to floods and storm surges and to a lesser degree to tsunamis. The facilities located in a zone where coastal flooding and wave action are the highest during hurricanes of categories 1 and 2 (and above). On average these kinds of hurricanes hit the *CI* every 2.23 years [1].

The results of our estimations of physical vulnerability of all identified critical facilities at *GC* indicates that only 12% of all analyzed critical facilities at *GC* are exposed to natural and man-made hazards with a high vulnerability, fig. 3. Explosions or leaks of the Airport Texaco Fuel Depot and the fuel pipeline, could impact the George Town Red Cross Building, the Caribbean Utilities and the Owen Roberts International Airport. An explosion of the Home Gas Terminal could damage the John Gray High School, which is also used as shelter in case of emergencies.

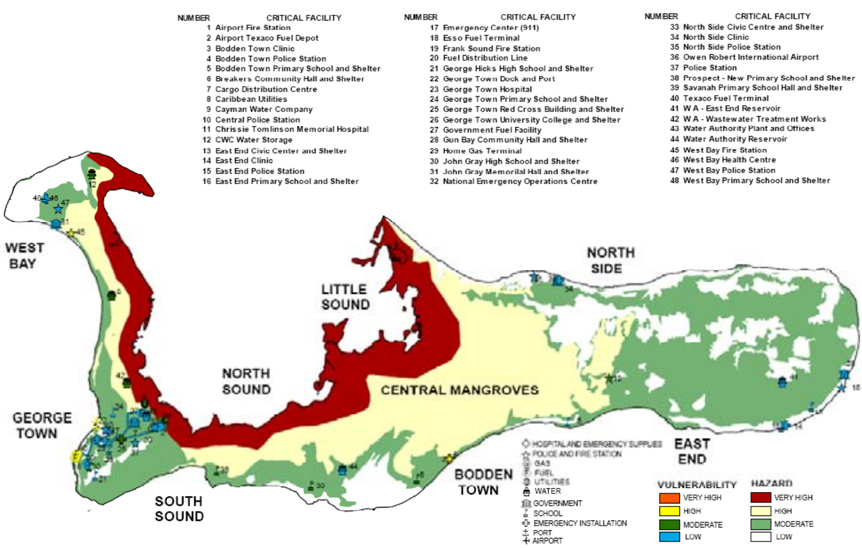

Figure 3: Areas showing the vulnerability and exposure of critical facilities to natural and man-made hazards in Grand Cayman.

In general, *GC* shows a very good level of protection of its critical facilities to natural hazards. The majority of the emergency response (82%) and government facilities (95%) as well as the utilities (85%) have physical vulnerabilities in the range from low to moderate. It is important to point out that none of the main critical facilities were rated with very high vulnerability.

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Analysis and prediction of building damage due to windstorms

N. O. Nawari
School of Architecture, College of Design, Construction and Planning, University of Florida, Gainesville, USA

Abstract

It's been more than five years since a major storm hit a major US city, however hurricane researchers have estimated that the next one could cause as much as $150 billion worth of damage.

An understanding of the damage mechanisms due to a variety of natural hazards such as wind, storm surges, and tsunamis windstorm hazard is integral to determining the best design and construction practices. Therefore, an anatomical analysis of a large suite of damaged structures in similar extreme events, such as Florida coastal areas, promises to reveal causes of failure in coastal construction and how best to prevent similar damage in the future.

Prediction and classification of hurricane buildings damage involves many sources of uncertain data that make it a difficult task using conventional prediction models. This work seeks to elucidate the application of data mining algorithms in the prediction and classification of damage due to hurricane and tornadoes forces. The research focuses on the conceptual and applied frameworks for the data mining models to assist in the prediction, assessment, and classification of buildings damages caused by server windstorms.
Keywords: wind storms, building damages, prediction, data mining.

1 Introduction

High winds, airborne projectiles, wind-driven water, sea surges, and flooding are among the hazards that threaten buildings and their occupancies. The record for US property insurance tells the story. Annual claims for wind damage claims tally hundreds of millions of dollars. Florida homeowners pay some of the nation's highest insurance premiums; in a recent poll, despite a housing crisis, an

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110031

economic crisis, a water crisis and an environmental crisis, Floridians named those premiums their number-two concern about the state's future, behind property taxes but ahead of jobs, education, health care and the dying Everglades.

It's not that coastal areas vulnerability is a secret. Continued development of coastal areas without consideration to the range of natural hazards, and the benefits and consequences of measures taken to mitigate them, will undoubtedly result in future storm and flood damages, and increased public expenditures for post-storm response and recovery.

Since Hurricane Andrew put most Florida insurers out of business and scared several national insurers out of the state, the state government has helped to hedge the risk of hurricanes. It provides subsidized insurance to 1.3 million high-risk homeowners who can't get private policies, an increase of more than 50% in just three years. It also has a Hurricane Catastrophe Fund that provides subsidized reinsurance to the state's private firms. But no one denies that the risk is real: it's been 80 years since a major storm hit a major Florida city, but hurricane researchers have calculated that the next one could cause as much as $150 billion worth of damage.

According to NIST technical note 1476, at the time of hurricane Katrina, there was no statewide building code in Louisiana, Mississippi, Alabama, or some parts of Texas, although some local jurisdictions within those states had adopted model building codes. The City of New Orleans had adopted the 2000 edition of the model building and residential codes issued by the International Code Council in January 2004. Significant damage was observed in many instances where the winds were lower than those levels cited in codes and standards suggesting that the there are many uncertainties involved in structural systems subjected to hurricane forces and illustrating the inadequacy of our current approaches. Thus, an understanding of the damage mechanisms due to a variety of natural hazards such as wind, storm surges, and tsunamis windstorm hazard is integral to determining the best design and construction practices. Therefore, an anatomical analysis of a large suite of damaged structures in similar extreme events, such as Florida coastal areas, promises to reveal causes of failure in coastal construction and how best to prevent similar damage in the future.

2 Anatomy of windstorm

Windstorm is a very complicated phenomenon. It is air and water in turbulent flow, which means that the motion of individual air or water particles is so erratic that in studying storm one ought to be concerned with statistical distributions of speeds and directions rather than with simple averages or fixed physical quantities. For analytical model, storm forces can be classified as one of a combination of:

- Wind Pressure
- Windborne Debris
- Falling objects

- Flood Pressure
- Rain Forces

The resistance of buildings to wind pressures has been the subject of considerable research and is addressed by building codes. However, normal design loads specified in these codes are substantially lower than those that occur during a windstorm. This is due to many sources of uncertainties involved in the computational model for the forces mentioned above. For instance, recent studies (Mosqueda and Porter [8]) have shown that damage due to Katrina hurricane extended beyond residential communities, with significant damage to engineered infrastructure, including buildings, roads and bridges, utility distribution systems for electric power and water, wastewater collection facilities, and vital communication networks, which are designed using standard design loads for gravity and lateral resisting elements. The ASCE 7 provision describes computational method for wind pressure using a number of coefficients that require considerable judgment to determine which pressure coefficients to use, how to determine tributary areas for cladding and framing elements, and whether building elements should be designed as part of the main wind force resisting system or components and cladding. The corners, edges, and eave overhang of a building are subjected to complicated forces as windstorm passes these obstructions, causing higher localized suction forces that are not considered appropriately in Building Codes. Moreover, there is no computational model or standard test protocol in the industry for the critical structural elements that addresses storm pressures generated by hurricanes or tornadoes.

3 Damage prediction

Buildings respond to windstorm forces in a variety of complex and dynamic ways. The windstorm destructions seems to be an intricate phenomenon associated with multidimensional uncertain dataset that is difficult to analyze entirely using classical approach**.**

Different researchers employed different methods to assist in the prediction of hurricane damages. For instance, Sill and Kozlowski [9] presented a method for predicting the percentage of damage within an area as a function of wind speed and various other parameters. The practicality of the proposed method is hampered by insufficient clarity and transparency. Huang et al. [2] presented a risk assessment strategy based on an analytical expression for the vulnerability curve. The expression is obtained by regression techniques from insurance claim data for hurricane Andrew. Khanduri and Morrow [5] also presented a similar method of damage assessment. Although such approaches are simple, they are highly dependent on the type of construction and construction practices common to the areas represented in the claim data. Burrus et al. [1] estimated the impact of low-intensity hurricanes as ‘business interruption’ of regional economies in North Carolina. A hurricane wind damage prediction model that incorporates a time-stepping component-based Monte Carlo simulation approach is being implemented for the FEMA HAZUS project (Lavelle et al. [6]). Hazards United States-Multi-hazard _HAZUS-MH, the FEMA hazard prediction program developed under contract with the National Institute of Building Sciences, uses GIS software to map and graphically depict hazard data, economic losses, and buildings and infrastructure damage from hurricanes, floods, and earthquakes. The system applies both loss estimation and risk assessment methodologies for a limited set of disasters. Although HAZUS-MH is equipped to model the probability and level of pre-incident risk, the system can neither support real-time response and recovery nor building information modelling (BIM) platform. Some studies also reported a loose prediction when compared with real data. Furthermore, using HAZUS to predict loss from a hurricane requires expert skills in meteorology to validate the input data used to develop the hurricane scenario and expert skills in wind and forensic engineering to assess the effectiveness and accuracy of the model output.

The hurricane damages seems to be a complex phenomenon associated with multidimensional uncertain data that is difficult to analyze entirely using classical approach. Data mining analysis offers an important tool in understanding and capturing details relationship between the different parameters involved.

4 Data mining analysis

Data mining is the process of extracting valid, authentic, and meaningful relationships from large quantities of data. It involves uncovering patterns in the data and is often tied to data warehousing because it attempts to make large amounts of data actionable.

Data elements fall into distinct categories; these categories enable making predictions classifications about other pieces of data. For example, building damages can be assessed from a large amount of data about the building sizes, location, geometric shapes, main materials, gravity and lateral resistive systems, and the intensity of storm. Knowing this basic building information, engineers can use data mining to models predictions about the expected degree of damages. One of the more difficult aspects of applying data mining in engineering practice has always been translating the theory into routine techniques.

A fundamental concept is that building a mining model is part of a larger process that includes all from defining the basic problem that the model will solve, to deploying the model into a working environment. This process can be defined by using the following basic steps: (i) define the problem, (ii) preparing data, (iii) defining models, (iv) validation and exploration, (v) deploying and updating models. The following diagram shows the process involved in the data-mining analysis:

The first step includes analyzing the requirements, defining the scope of the problem, defining the metrics by which the model will be evaluated, and defining the final objective for the data mining project. These tasks can be summarized in the following: Defining the datasets for the analysis, Identifying the attributes of the dataset that we want to try to predict, What pattern and associations are we seeking?

The second step involves the preparation, which may include calculating the minimum and maximum values, calculating mean and standard deviations, and looking at the distribution of the data. Microsoft SQL2008 server has a data Source View Designer in Business Intelligence (BI) Development Studio that contains several tools that allows such data exploration.

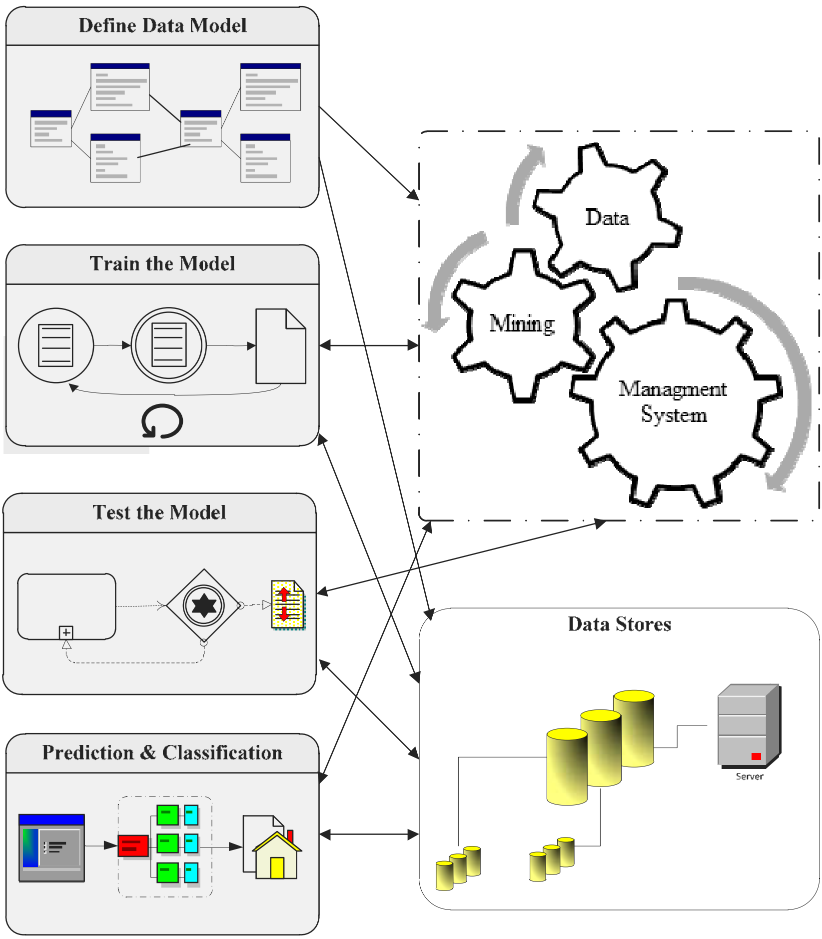

Figure 1: Data mining analysis process.

Before starting the analysis, the model data must be randomly separate into training and testing datasets. This step can be achieved by using the Percentage Sampling Transformation service available with SQL 2008 server as a part of the Integration Services. The Percentage Sampling Transformation creates a sample dataset by selecting a percentage of the transformation input rows. The sample dataset is a random selection of rows from the transformation input, to make the resultant sample representative of the input. The training dataset is utilized to build the model, and the testing dataset to verify the accuracy of the model.

A data mining model is typically defined by specifying input columns, an identifying column, and a predictable column. Alternatively, once can define these columns in a new model by using the Data Mining Extensions (DMX), or the Data Mining Wizard in BI Development Studio. This is known as mining structure that defines the data domain from which mining models are built. A single mining structure can contain multiple mining models that share the same domain. This structure contains information such as data type, content type, and how the data is distributed.

After defining the structure of the mining model objects, training starts by populating the empty structure with the patterns that describe the model. Patterns are found by passing the original data through a mathematical algorithm. SQL Server 2008 contains different algorithms. The data mining algorithm is the mechanism that creates mining models. To create a model, an algorithm first analyzes a set of data, looking for specific patterns and trends. The algorithm then uses the results of this analysis to define the parameters of the mining model.

In summary, a mining model is defined by a data mining structure object, a data mining model object, and a data mining algorithm. Microsoft SQL Server 2008 Analysis Services (SSAS) provides several algorithms for use in data mining solutions: Decisions Trees, Clustering, Association Rules, Naïve Bayes, and Neural Network.

5 Prediction

Most of the building damage predictions have been too focused on treating single hazards in isolation and must be broadened to include the capacity to account for multiple hazards. The multi-hazard approach takes into account the mitigation strategies for various hazards simultaneously within a balanced approach. The first step in multi-hazard prediction is to determine the risks that are specific to a structure’s site. The site must be analysed based on geographic location and previous history. The loads, building type, shapes, size and form, degree of exposure and resulting structural response associated with each potential hazard a structure may encounter must be described and quantified in the data model. Knowledge of the damage mechanisms is imperative in determining how hazards relate to each other and what aspects of the building are particularly affected. These data are partially described in the database structure depicted in figure 2 below.

The relationship between geographic locations, form, sizes and geometric shapes of concrete, steel, timber and masonry residential building including their primary gravity and lateral resistive systems, the intensity and type of storms, and the degree of damages can be analyzed using the data mining models techniques suggested herein to provide supportive damage prediction system.

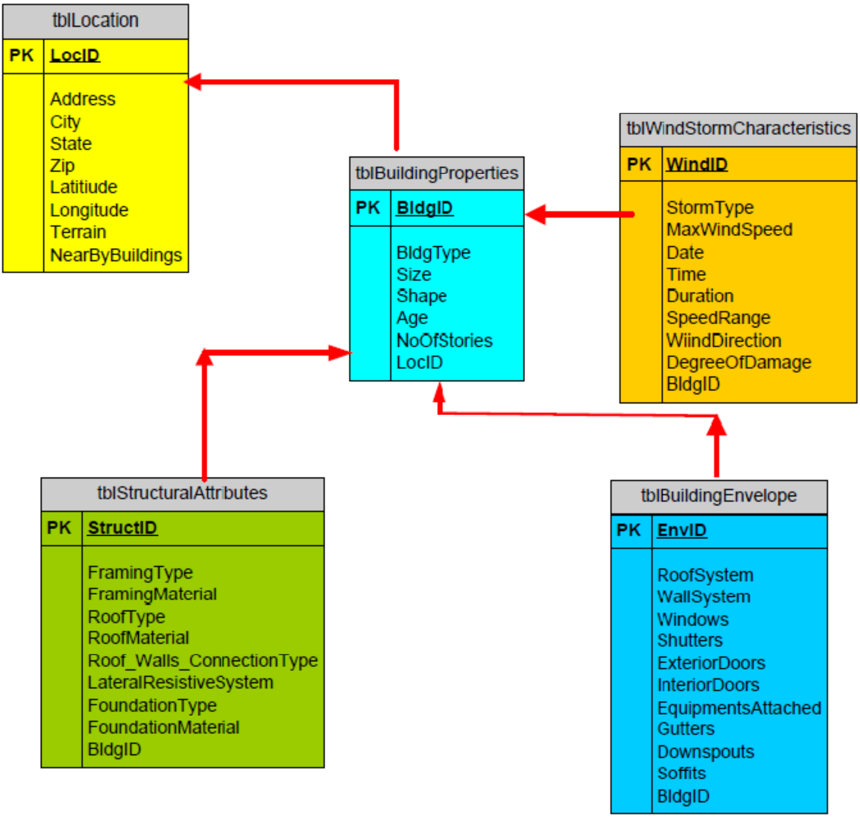

Figure 2: Part of the database diagram for the data mining analysis.

The output prediction vector is based on the damage categories specified by FEMA320. These categories are modified to include the distinction between envelope and structural damages of buildings. In contrast to FEMA320, ten damage categories are proposed in this study.

(1) **Minimal:** No real structural damage is done. Minor building envelope damages may occur (less than 5%).
(2) **Low Moderate:** 6%–10% Roof and other envelope components are damaged.
(3) **Moderate:** 11%–20% Roof and other envelope components are damaged.
(4) **High Moderate:** more than 20% Roof and other envelope components are damaged.
(5) **Low Extensive:** less than 10% Structural damage is done along with damages to envelope.
(6) **Extensive:** less than 20% Structural damage is done along with damages to envelope.

(7) **Low Extreme:** Extensive damage is done to many envelope components (21%–30%) accompanied by structural damages (21%–30%)

(8) **Extreme:** Extensive damage is done to many envelope components (31%–50%) accompanied by structural damages (31%–50%) that may result in complete building failure.

(9) **Very Extreme:** Extensive damage is done to many envelope components (51%–60%) accompanied by structural damages (51%–60%) that may result in complete building failure.

(10) **Catastrophic**: Envelope damage is extensive and widespread (> 60%). Structural damages considerable and there are complete to near complete buildings failure.

Many researchers have noted that code-based design, as it exists today, may not be sufficient in many coastal areas (Kareem [4], Lee and Rosowsky [7]). Instead, performance-based design is receiving attention in areas affected by multiple hazards. Avoiding collapse and maintaining occupant safety may not be the only expectations. Therefore, the design process must incorporate the relationship between performance and global risk of failure. Exceeding the requirements of local and national building codes may increase initial construction costs, but long-term benefits in overall robustness and resiliency of a structure may easily outweigh these initial costs.

6 Conclusions

Code-based building design, as it exists currently, may not be sufficient in the United States Gulf and Atlanticcoastal areas. These areas where most of the country's windstorm related fatalities have occurred are also now experiencing the country's most significant growth in population and buildings. Under these conditions, multiple hazards with which a building may be faced must be considered in all aspects of design and construction. A multi-hazard design approach would ensure that design strategies used to mitigate one hazard would not affect the structures ability to resist another hazard. The probabilities of failure and consequences of failure can be compared to determine the best way to lower the overall risk of failure. An anatomical data mining analysis will provide such information and assist to design strong, multi-faceted structural systems that mitigate damage from many hazards.

The relationship between windstorm and building damages sited raises many uncertainties about current building design and construction practices. Application of data mining analysis provide a supportive tool to handle uncertainty and discover hidden relationships and rules that assist in classifying, predicting and associating multihazard building damages and windstorm patterns. The system could also be instrumental in updating Building Codes and standard. Buildings that use multihazard engineering strategies in their initial design stages will be able to withstand loads resulting from various circumstances and will maintain structural integrity for years longer than traditionally designed buildings. From the severity of destructions shown in recent hurricanes and tornadoes, it is apparent that Building Codes and Standards need to re-address windstorm resistive systems.

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Seismic performance analysis of lifeline systems

M. Faraji & J. Kiyono
Graduated School of Engineering, Kyoto University, Japan

Abstract

Seismic risk assessment of lifelines is considerably more complicated than that of a single structure on account of the geographical spread of lifelines. Lifeline risk assessment requires knowledge about ground-motion intensities at multiple sites. This study considers the seismic performance analysis of lifeline network systems. Seismic damage estimates of the potable water and electric power networks of the Bam city will be calculated for the expected earthquake scenario and the results will be utilized to assess the performances of the topological models of the networks. The study will first include collection of lifeline utility network data in GIS format. Seismic damage analysis will be made by defining fragilities of the network components and the ground motions generated by the scenario earthquake. The damage estimates will be utilized in the post-seismic state of the networks for disaster management countermeasures and activities.
Keywords: lifelines, seismic performance, risk assessment, fragility curve, probabilistic.

1 Introduction

Lifelines are the systems that relate to daily life needs, like water-supply, power, telecom, traffic, gas-supply, sewage and heat-supply, and so on. Strong dependence on lifeline system is one of the distinctive characteristics of modern urban area. The issue of vulnerability of critical infrastructures has recently attracted considerable attention from both the academic and policy-making spheres. A systematic method for addressing risk assessment and risk management is the, so-called, Probabilistic Risk Analysis (PRA), which concerns the performance of a complex system in order to understand likely outcomes and its areas of importance. PRA has historically been developed for situations in which measured data about the overall reliability of a system are

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110041

limited and expert knowledge is the next best source of information available. It is valuable because it does not only quantify the probabilities of potential outcomes and losses, but it also delivers reproducible and objective results. There are many obstacles for the implementation PRA. One of the main reasons is lack of input data [8].

2 Lifeline performance after 2003 Bam earthquake

Bam is a city in south east of Iran. The 2003 Bam earthquake with magnitude Mw=6.5 destroyed most of the city of Bam and nearby villages. The earthquake was by far the most devastating earthquake in the history of the region around Bam. The maximum uncorrected accelerations recorded at Bam station were 0.82g, 1.01g and 0.65g in the longitudinal, vertical and transverse directions, respectively.

The earthquake mainly affected power, water, and communication networks in the epicentral regions, fig. 1. Damaged substation of the power transmission system and numerous electrical transmission concrete poles in the Bam electric distribution system, caused blackouts in city within hours following the earthquake and power had not been restored for several days. Water systems in Bam and Baravat experienced heavy damage and the water supply was cut off for a long duration due to extensive pipe breaks. Bam water system, on the other hand, experienced major damage mainly because of the old asbestos cement distribution lines. There were several breaks in the water distribution systems and minor damage to deep wells. The elevated water tank in the old section of the city was severely damaged. Although Bam have not had gas distribution network during earthquake [4].

The damage to roads, bridges, railway and airport was minor. Many streets and most of the alleys were blocked after the earthquake due to debris from the damaged buildings. The airport was out of operation for a few hours after the earthquake due to damage to the airport control tower but later played a major role in the rescue and relief operations [3].

Figure 1: Damaged Bam asbestos cement water pipe and electric substation.

3 Seismic hazard analysis

In order to assess risk to a structure from earthquake shaking, we must first determine the annual probability or rate of exceeding some level of earthquake ground shaking at a site, for a range of intensity levels [2]. The somewhat complicated probabilistic evaluation could be avoided if it was possible to identify a “worst-case” ground motion and evaluate the facility of interest under that ground motion. This line of thinking motivates an approach known as deterministic hazard analysis.

3.1 Deterministic seismic hazard analysis

The deterministic method is the standard approach in which effects from the largest earthquake expected (MCE) are the primary focus. Note that a scenario earthquake is suggested as the central concept for the ‘deterministic’ or ‘maximum credible earthquake’ in seismic hazard assessment [1].

The use of the MCE ensures that effects from all other magnitudes are explicitly considered. In other words, by virtue of designing a structure to withstand the MCE, it will automatically withstand all other (smaller) earthquakes. MCEs from all faults in the region are considered. Effects from all MCEs are compared, and the ones that would impact the most selected as the design earthquake. In the case of Bam city it is considered that Bam fault as a scenario earthquake, fig. 2. Bam fault caused the earthquake of 2003 is located 3 km far from city centre with magnitude 6.5.

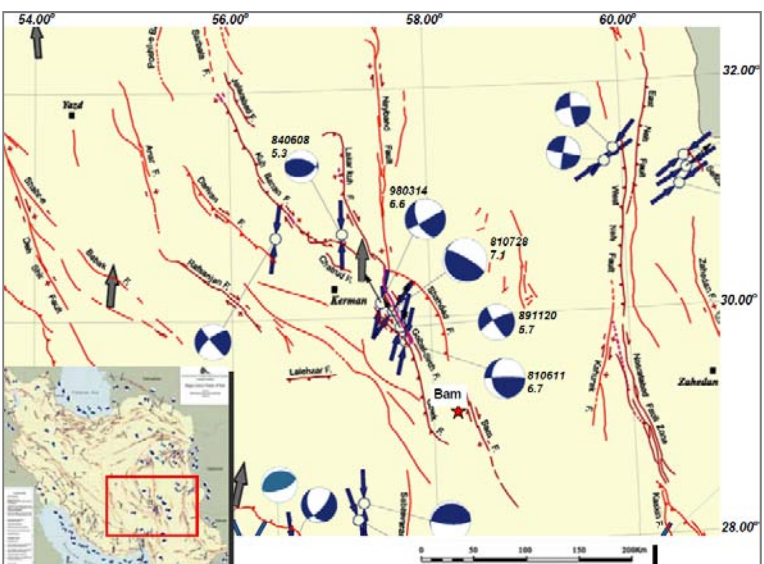

Figure 2: Regional seismology of Bam city (Courtesy of IIEES [7]).

3.2 Probabilistic seismic hazard analysis

While the choice of a “worst-case” earthquake can be difficult and subjective, an even greater problem with deterministic hazard analysis is the choice of worst-case ground motion intensity associated with that earthquake. With probabilistic seismic hazard analysis (PSHA) it is no longer searching for elusive worst-case ground motion intensity. Rather, it will consider all possible earthquake events and resulting ground motions, along with their associated probabilities of occurrence, in order to find the level of ground motion intensity exceeded with some tolerably low rate [2]. At its most basic level, PSHA is composed of; Identify all earthquake sources capable of producing damaging ground motions, Characterize the distribution of earthquake magnitudes, Characterize the distribution of source-to-site distances associated with potential earthquakes, Predict the resulting distribution of ground motion intensity as a function of earthquake magnitude, distance, etc, and finally Combine uncertainties in earthquake size, location and ground motion intensity, using a calculation known as the total probability theorem.

3.3 PSHA of Bam city

It is interested in all earthquake sources capable of producing damaging ground motions at the site. These sources could be faults, which are typically planar surfaces identified through various means such as observations of past earthquake locations and geological evidence. If individual faults are not identifiable, then earthquake sources may be described by Areal Regions in which earthquakes may occur anywhere. Once all possible sources are identified, it can identify the distribution of magnitudes and source-to site distances associated with earthquakes from each source, fig. 3.

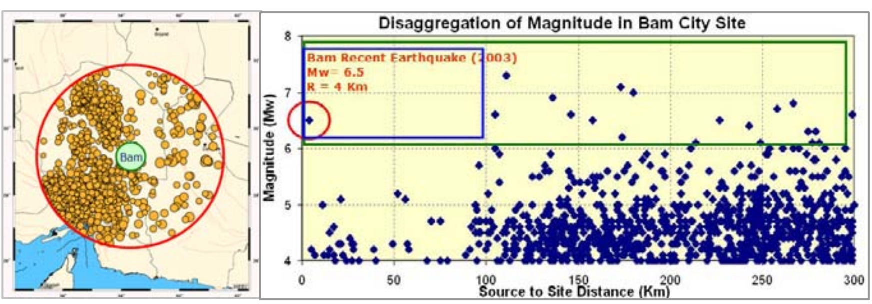

Figure 3: Earthquakes in southeast Iran (Epicentres from online IIEES).

In this study an areal source within a 300 km radius is considered that is capable of producing earthquakes with a variety of magnitudes. The area source produces earthquakes randomly and with equal likelihood anywhere within 300 km of the site. Areal sources are often used in practice to account for “background” seismicity, or for earthquakes that are not associated with any specific fault. The number of 1789 records was gathered. It is considered that the source produces events with M ≥ 4 (783 records) at a rate of 0.02 events per year. The distribution of those earthquakes follows the bounded Gutenberg-Richter model (eqn. (1)).

$$log\ \lambda_m = a - bm \tag{1}$$

It is now quantified the distribution of potential earthquake magnitudes and locations, but we are interested in analyzing ground motions, not earthquakes.

Therefore it is considered a suitable ground motion prediction model depending on study area. Ghodrati *et al*. [6] proposed predictive model especially for Iran seismic zones, eqn. (2), for the mean of log peak ground acceleration (PGA) in units of gal and peak ground velocity (PGV) in units of kine [6].

$$ln\, y = C_1 + C_2 .M_s + c_3 ln[R + C_4 exp(M_s)] + C_5 R \tag{2}$$

It is used total probability theorem, eqn. (3), to perform the PSHA calculation for PGA and PGV, using the Ghodrati *et al*. attenuation relation ground motion model. PGV and PGA hazard curve for Bam city is illustrated in fig. 3.

$$\lambda(IM > x) = \lambda(M > m_{\min}) \int_{m_{\min}}^{m_{\max}} \int_{0}^{r_{\max}} P(IM > x \mid m, r)\, f_M(m)\, f_R(r)\, dr\, dm \tag{3}$$

Where $\lambda(IM > x)$ is the rate of $IM > x$, $\lambda(M > m\ \min)$ is the rate of occurrence of earthquakes greater than $m_{\min}$ from the source and $f_M(m)$ and $f_R(r)$ are probability density functions for magnitude and distance, and it is integrated over all considered magnitudes and distances.

PSHA parameters, based upon topological properties taken from risk assessment, are computed and then visualised on a GIS. Lifeline systems are of large scale, complex and geographically distributed; use of GIS for the integration and manipulation of all available data has become more popular. Moreover, GIS plays a double role: in the first instance GIS software is a vital

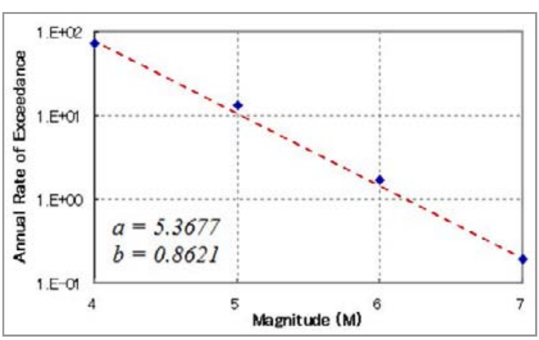

Figure 4: Distribution of observed earthquake magnitudes, along with eqn. (1).

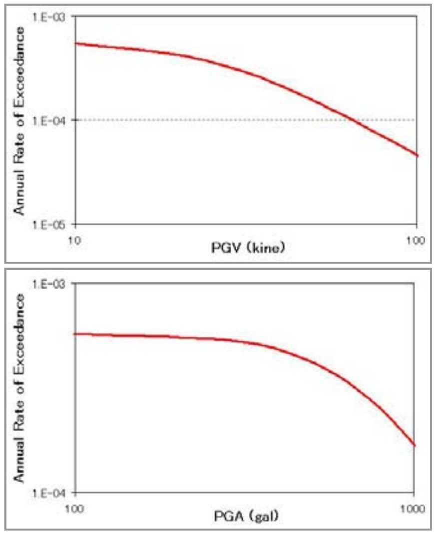

Figure 5: PGV and PGA hazard curve for Bam city, along with eqn. (3).

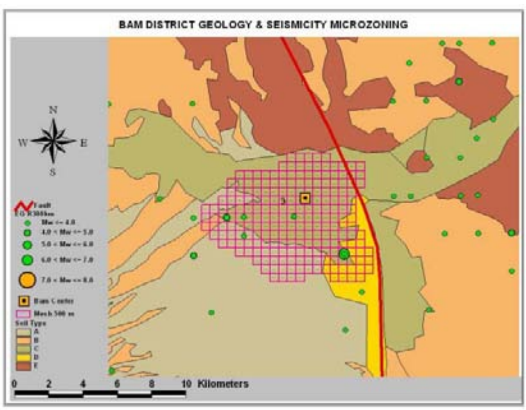

Figure 6: Bam district geology, seismicity and the city grid mesh in GIS.

tool for encompassing the spatial characteristics of infrastructure systems; and as such, it provides the topology of the network accompanied by additional information. Finally, having numerically processed, GIS can again be used for the effective visualization of results of the analysis in terms of various forms of mapping that allow users to examine spatial characteristics. Therefore, Bam district geology, seismicity and lifeline systems are modelled in GIS, fig. 6. Bam city is modelled by grid mesh 500 m dimension.

The description of the seismic hazard map is a monotonic function with the return period *T* and the exposure time *n*. The return period (or recurrence interval) is the average time span between two events of a given magnitude at a particular site. The exposure time usually equals the expected life of the structure. In order to calculate the design life expectation of the structure, both these parameters (as well as the return period of the event) must be employed when calculating the risk of the structure with respect to a given event [5]. The risk assessment is thus the likelihood of at least one event that exceeds the design limits of the structure in its expected life. In this study, Bam seismic hazard maps calculated for 475 return period and 50 years of exposure time corresponds to 10% probability of exceedance, fig. 7.

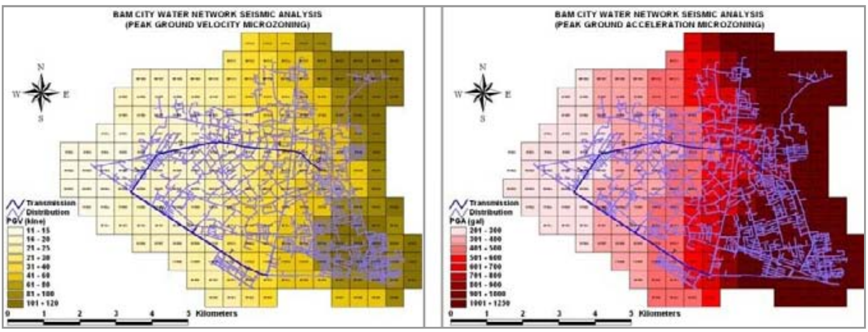

Figure 7: Bam PGV & PGA hazard map calculated for 475 return periods.

In fact, there is 90% chance that these ground motions will not be exceeded. This level of ground shaking has been used for designing ordinary buildings in high seismic areas.

4 Lifeline systems damage assessment

The probability of physical damage to a facility is modeled by the seismic fragilities for various lifeline facilities. The damages of lifeline networks are usually showed by the correlation of damage ratio and earthquake parameter as fragility curves. Most researches of fragility curves are usually using *PGA* or *PGV* as earthquake parameter.

4.1 Bam water network

The Guidelines prepared by the American Lifeline Alliance suggests that damage to water pipe caused by strong ground motion can be expressed as a function of PGV, eqn. (4).

$$RR = K\ (0.00187)\ PGV \tag{4}$$

where RR is the repair ratio, which is the number of pipe breaks per 1000 feet (305 m) of pipe length, K1 is a coefficient determined by the pipe material, pipe joint type, pipe diameter and soil condition, and PGV has the units of in/sec. Generally water pipes installed in the Bam area were cement-asbestos and some of them were PVC and polyethylene. Only large-diameter water mains, with diameters from 10 inches to 25 inches (250–600 mm), were cast and ductile iron. Considering the typical water pipes, pipe material, pipe joint type, pipe diameter and soil conditions in Bam, it is assumed various K1 and calculated water network damage ratio in each 500 m grid mesh, fig. 8.

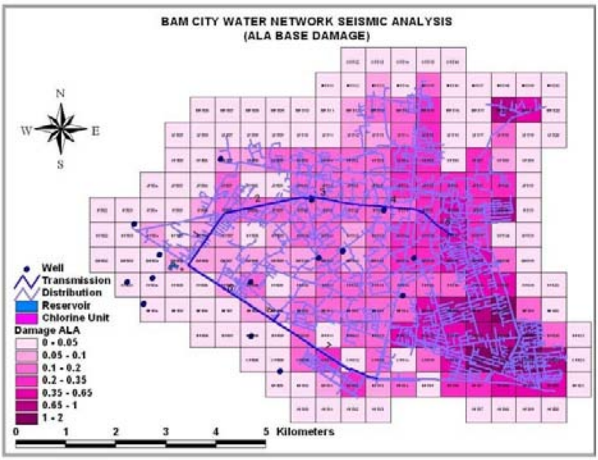

Figure 8: Bam water network damage ratio (based on ALA-2001).

Figure 9: Bam buildings damage after earthquake (survey by JICA 2004).

Assuming that occurrence of one rupture impairs the pipeline functionality, fig. 1, and based on JICA study team report about building damage rate in Bam earthquake, as shown in fig. 9, the high damaged region in case of building is very similar to the region defined by high damage water pipelines, fig. 8. The fact that districts experiencing a high level of pipeline damage also experienced a high level of building damage implies that damage patterns were dominated by the influence of variations in strong motion from district to district. Therefore it seems that in case of network input data lack and without any lifeline damage assessment analysis, using the building damage database prepare suitable rough network damage estimation for disaster management and post earthquake activities such as emergency water supply.

4.2 Bam electricity power network

Electricity power network of Bam city is supplied by a 230 kv transmission line. There is a 230/132 kv substation in the south part of the city, fig. 7. Bam power distribution network is about 600 km length and divided to two levels, medium (20 kv) and low voltage (220 v). Because of lack of data, in this study only the substation is considered to damage assessment.

In the case of electricity power system, it is used the fragility curves for the substations and power plants. The shape of the fragility curve for the given element is dependant on the damage state. More severe damage states correspond to the lower probability of exceedance at the same PGA. Damage states as defined in HAZUS are dependent on the type of element and the level of the damage of its subcomponents.

Fragility curves of the substations are classified according to the voltages assigned to the substation and according to whether all subcomponents of the substations are anchored or not. Substations are classified according to their voltage rating: from low voltage (<150 kV), medium voltage (150 – 350 kV) and high voltage (>350kV). Furthermore, we have to define the subcomponents of the substation. In case of Bam electricity power substation, it is considered medium voltage and unanchored. According to the location of the substation, affected PGA is about 574 gal. Thus by using medium voltage and unanchored fragility curve, fig. 10, the probability of physical damage is about 0.96.

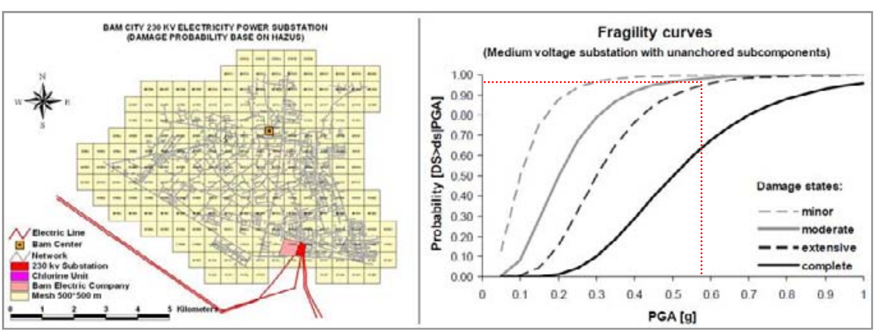

Figure 10: Bam 230 kv electric substation and HAZUS fragility curve.

In fact, the bam substation is damaged in this hazard level (475 years). Although, this level of ground shaking has been used for designing ordinary buildings in high seismic areas and in case of higher importance facilities such as hospitals and lifeline infrastructures must be designed for hazard events with higher return period than 475 years. Hence Bam electric substation was extensive damaged inevitably due to 2003 earthquake, fig. 1.

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5 Conclusion

Given the importance of lifeline systems to the society; reliable seismic assessment of those systems becomes crucial for better preparedness and disaster management. Modeling the seismic response of is one approach towards more accurate anticipation of the effects of earthquakes in the urban areas. This paper summarizes the framework of lifeline seismic analysis especially PSHA methodology and revises the probabilistic seismic hazard maps of Bam city. After considering the active fault and considering appropriate attenuation relationships, PGA and PGV were calculated in 475-year return period for 500 m grid mesh. The repair ratio of buried pipelines is computed for each cell based on ALA-2001, as an earthquake performance of water network. According to the location of the Bam electric substation, the probability of physical damage is about 0.96, therefore is damaged in 475 years hazard level. The results consistent with happened damages after the earthquake. Districts experiencing a high level of distribution network damage also experienced a high level of building damage, therefore it seems that in case of network input data lack and without any lifeline damage assessment analysis, using the building damage database prepare suitable rough network damage estimation for disaster management and post earthquake activities such as emergency water supply.

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Real-time landslides monitoring and warning using RFID technology for measuring ground water level

S. Hosseyni[1,2], E. N. Bromhead[2], J. Majrouhi Sardroud[2,3]
M. Limbachiya[2] & M. Riazi[4]
[1]*Islamic Azad University, Azadshahr Branch, Iran*
[2]*School of Civil and Construction Engineering, Kingston University, UK*
[3]*Islamic Azad University, Central Tehran Branch, Iran*
[4]*Consultant Engineer, UK*

Abstract

Across the world, economic and social landslide losses have increased as human development has expanded into unstable onto hill slopes. Every landslide catastrophe produces a significant loss to infrastructures, services and buildings as well as resulting in large numbers of casualties and fatalities. Although ground water level is often a primary controlling factor in landsliding, modeling of ground water is difficult due to the complex internal geology in most landslides. There are different approaches to locate the ground water table. Field observations are vital. This research has focussed on the utilization of integrated applications of Radio Frequency (RF) technologies such as Radio Frequency Identification (RFID), with ultrasonic sensors for accurate and timely identification and monitoring of ground water level in slopes and landslide susceptible areas. RFID integrated with ultrasonic and temperature sensors provide an opportunity to monitor groundwater in landslide susceptible areas on a real-time basis. The transmission of data to the central database can be carried out with the help of Global System for Mobile Communications (GSM), and the collected data can be used for slope stability analysis.
Keywords: ground water level, landslide monitoring, ultrasonic, RFID.

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110051

1 Introduction

Landsliding is a complex geological and geomorphological process that occurs when the resistance of the soil or rock deteriorates. Over the past few years, the incidence of landslide disasters increased as a result of human development onto hill slopes. In comparison to earthquake their effects are more easily mitigated. Monitoring and early warning systems are important. Although stabilization projects are an alternative treatment for unstable slopes, they are sometimes impracticable and not cost-effective. It can be argued that establishing an adequate monitoring and early warning system is a better an alternative option. Appropriate monitoring not only throws light on the issue of early warning, but also can help in understanding landslide processes.

There are different approaches to detect surface or subsurface movement such as: the use of survey markers; extensometers; inclinometers; analogue and digital photogrammetry, both terrestrial and aerial; and Interferometric Synthetic Aperture Radar (InSAR) and Ground-Based Synthetic Aperture Radar (GB-SAR) and recently Web Geographical Information System platform (WebGIS) [1–3].

Among the main causal factors of landslides, the temporal variation of the groundwater level plays an important role on slope instability, so that it can be said that the ground water level is often the primary controlling factor in landslide occurrence. Recently, investigations have been carried out for modelling and estimating groundwater level in various conditions. The distributed three-dimensional groundwater model MODFLOW has been applied to evaluate the groundwater processes of the hydrogeological system within GIS [4]. Soil moisture was assessed by an airborne scatterometer by Blumberg et al. in 2000 [5]. They developed a multi-channel system as a remote sensor for mapping soil water content. In 2002 dynamic groundwater movement was monitored using Ground Penetration Radar (GPR) by Sato and Lu [6]. Water behavior inside the soil was simulated by a two-dimensional simulation model for prediction of rainfall triggered landslides [7]. Groundwater numerical modeling has been used to understand the patterns of groundwater flow in slopes and their impact on slope stability by several researchers [8]. An investigation of slopes endangered by rainfall induced landslides using high-resolution 2D and 3D electrical resistivity tomography (ERT) was carried out to derive detailed subsurface images by Friedel et al in 2006 [9, 10]. Multi-temporal images for groundwater level monitoring in arid areas was used in 2008 by Pan et al. [10]. A time domain reflectometry-based probe was used for monitoring water content in a high-clay landslide by Stangl et al. in 2009 [11]. The results from soil moisture probes and water levels revealed the surface infiltration process in an unsaturated soil so that the mechanism of failure of rainfall-induced landslides could be understood by Tu et al. [12] in the same year. Environmental sensors and sensor networks to develop water and salinity budgets for seasonal wetland real-time water quality management were investigated in 2010 by Quinn et al. [13].

In this research RFID and sensor technologies have been combined with other traditional groundwater monitoring techniques and rainfall gauges to provide real-time groundwater level information correlated rainfall. This cost effective and low power consumption system provides a fit-for-purpose approach to get the basic data for monitoring groundwater level change from distance. Data can be captured and saved continuously, far from the site in any weather condition even during a landslide. For best effect, automated record data systems should be coupled with dynamic software to acquire and save real-time continuous data and to visualise groundwater table areas. It gives a regional seasonal picture of groundwater level in the endangered areas. In addition, when the system is combined with rainfall gauges, it has the capability of providing reliable data for understanding the mechanisms and processes in which shallow and rainfall triggered landslides occurred, and subsequently the real relationships between rainfall infiltration and groundwater table can be obtained.

2 Problem statements

Landslide monitoring systems usually concentrate on ground movement, as this gives direct indication of developing instability. Groundwater monitoring on the other hand, needs to be interpreted through an appropriate stability model to be useful. It is important, therefore that if ground water monitoring is undertaken, that the measurement of water level is made in real time and is transmitted to a safe remote location for processing. The problems therefore lie within the areas of both data collection and transmission.

The following section describes the three basic technologies used in a data collection and transmission system. They are an ultrasonic sensor to measure the depth to the water table, driven by an RFID tag that can be activated remotely, and the GSM connection for data transmission.

3 Wireless technologies

Recent technological advancement in wireless sensor technologies and data acquisition systems provide potential for advanced consistent data collection and communication, and are both technically and economically feasible and viable [14].

Ultrasonic sensors are widely used in industrial applications to measure object distance recently. The operating principle is based on the measurement of the Time of Flight (T.o.F.), which is the time required for an ultrasonic wave to travel from a transmitter to a receiver. In T.o.F. technique, object distance (D) from the receiver is evaluated by $D = V \times T.o.F.$ where V is the sound velocity [15].

RFID is a method of remotely storing and retrieving data by utilizing radio frequency in identifying, tracking, and detecting various objects [16]. During the last few years, RFID technology has already taken its place as a prototype in civil engineering for identification and data acquisition [17] and has been successfully used in the areas of manufacturing, distribution, the supply chain, agriculture, transportation, and healthcare. An RIFD system consists of tags (transponders) with antenna, a reader (transceiver) is also antenna, and a host terminal. The RFID reader acts as a receiver and transmits an electromagnetic field that ‘‘wakes-up’’ the tag and provides the power required for the tag to operate [18]. An RFID tag is a portable memory device located on a chip that is encapsulated in a protective shell and can be attached to any object which stores information about the object. Tags consist of a small integrated circuit chip coupled with an antenna to enable them to receive and respond to radio frequency queries from a reader. RFID tags can be classified into active tags (battery powered) and passive tags, which powered solely by the magnetic field emanated from the reader and hence have an unlimited lifetime. Reading and writing ranges are depend on the operation frequency (low, high, ultra high, and microwave). Low frequency systems generally operate at 124 KHz, 125 KHz or 135 KHz. High frequency systems operates at 13.56 MHz and ultra high frequency (UHF) and use a band anywhere from 400 MHz to 960 MHz [19]. Tags operating at ultra high frequency (UHF) typically have longer reading ranges than tags operating at other frequencies. Similarly, active tags have typically longer reading ranges than passive tags. Active tags have an internal battery source and therefore have a shorter lifetime of approximately three to ten years [18]. The reader, combined with an external antenna, reads/writes data from/to a tag via radio frequency and transfers data to a host computer [20]. RFID tags are not damaged easily and do not require line-of sight for reading and writing, they can also be read in direct sunlight and survive harsh conditions, reusable, and permit remote access [21].

GSM is a worldwide standard for cellular communications. One of the current available technologies for mobile data transfer is General Packet Radio Systems (GPRS). GPRS is a packet switched “always on” technology which allows data to be sent and received across a mobile telephone network almost instantly [22].

4 Architecture of the proposed system

The RFID-based pervasive system developed in this research is divided into three major parts, firstly the field or on-site monitoring system and secondly the office data processing system. The on-site system mainly consists of two types of hardware components; namely, (i) Groundwater Level Box (GWL-box) consisting of the transmitter/receiver, GSM module; (ii) digital rainfall gauge; (iii) Leveling Package (LP) which consists of an active RFID tag coupled with ultrasonic sensor, this also equipped with a temperature sensor. GSM communication technology is the second part of the mobile pervasive system where the information is retrieved from transmitter/receiver device and is transferred to the server using GPRS. Finally, the Data Processing System consists of two servers, the application server (e.g. GIS system) and the database server with warning system. The architecture of the system and the schematic model of collection, transmission and managing of data are shown in figure 1.

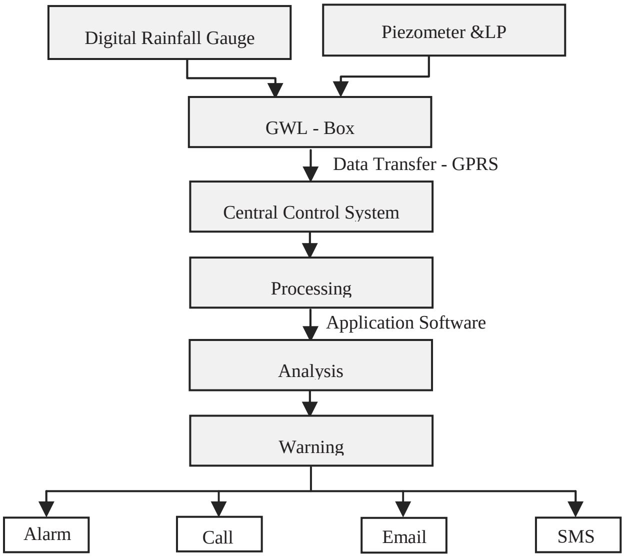

Figure 1: The system implementation flow diagram.

5 Implementation

To meet the requirements of real-time monitoring of the changes in pore water pressure in a given area, an intelligent network system gathers the required information continuously. The monitoring system, which combines sensor technologies with traditional method of groundwater level monitoring, piezometers, consists of the following subsystems:

5.1 System installation and setup

First of all, piezometers are located based on the geological and topographical maps of the area, using expert judgment. The numbers and location of piezometers can also be optimized using a neural network algorithm if necessary. For levelling up the water inside the piezometers, they have been left to stabilise. The main part of the proposed system is placed in the piezometer. The main function of this part is measuring the water level. This part of the system which is named LP consists of an active RFID tag coupled with an ultrasonic sensor equipped with a temperature sensor. This subsystem floats on the existing water in the piezometer using a small balloon. It has capability to receive RF waves and sends RF-ultrasound waves to and from the transmitter and receiver. Figure 2 illustrates a schematic scheme of the automated groundwater level monitoring system.

The heart of the system is the Groundwater Level Box (GWL-box). This includes a transmitter/receiver and GSM module. The GWL-box sends the collected data continuously, however, in order to detect the box from landsliding it is highly recommended to install the box on a concrete platform and in the more stable zone of the area. The transmitter/receiver can collect the data regarding the water level from the piezometer and also get rainfall data from the recorder by wire.

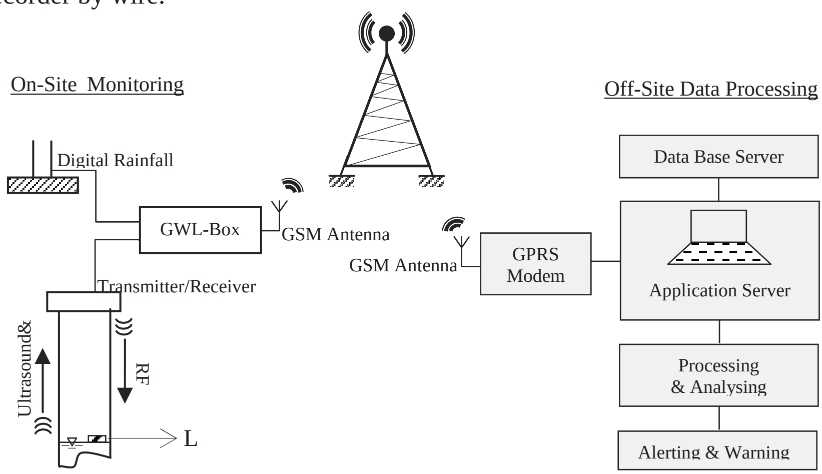

Figure 2: Schematic scheme of the automated groundwater monitoring system.

As illustrated in figure 3, the transmitter and receiver can be packed and secured as the cap of the piezometer. The main performance of this part of the system is sending RF waves towards the active RFID-Sensors (LP) and receiving RF and ultrasound waves from the LP as well as transfer of the collected data to GWL-box.

The last on-site subsystem which is installed and connected directly to GWL-box is a digital rainfall recorder. This peripheral device has the capability of data retrieval by data shuttle directly to GWL-box and is equipped with a solar power supply.

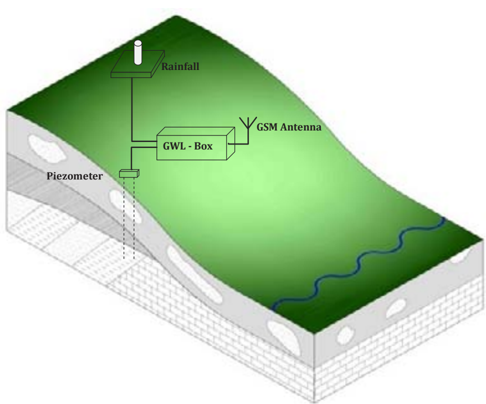

Figure 3: Schematic model of system installation.

This linkage between the two subsystems, LP and digital rainfall gauge, provides the advantage of continuous data collection even in adverse climatic conditions, so that sophisticated data collection is possible for slope instability prediction in the future.

5.2 Triggering and depth calculation

As it was mentioned, the Leveling Package (LP) floats on the water inside the piezometer measuring its water level. On the measurements of T.o.F. for RF to estimate the distance of tag from the receiver, the delay is attributed to the speed of RF (very fast travelling) signals in the space. In order to find a solution for this issue and to have a more accurate measurement for distance, an ultrasound signal is used to measure the distance of sensor from the receiver. Therefore, an estimation of distance starts with a query from transmitter and at the same time a timer starts and the tag responds to the ultrasound signal within a short time after a querying of the receiver. Thus, the signal travels with the speed of light in the forward direction and with the speed of ultrasound in the backward direction where the speed of ultrasound signals is about 340 m/s which is significantly slower than the speed of light (one million times slower than the speed of light). Therefore small delays identified by scheduling the sensor do not cause an error in estimation of distance and we can ignore the component of the delay recognized by the small processing or scheduling delay at the sensor, or the propagation delay of RF signal in the forward direction. The ultrasound signal does not carry in digital information, thus RFID active tag has been selected for transferring data such as temperature which is connected to the tag.

The intensity of the ultrasonic wave generated by the transmitter and the sensitivity of the receiver depends on the temperature of the environment which leads to a strong temperature dependence of the reflected intensity. The propagation time also depends on the temperature of the propagation environment (i.e. air).

The speed of sound in air actually depends on the temperature of the air. As a standard, it is accepted that the speed of sound is 340m/s at 15°C. In order to calculate the speed of sound at a different temperature, this formula is used:

$$v = 331.5\text{m/s} + 0.6T$$

which “v” is the velocity of sound (m/s) and T is the temperature (°C).

For example the properties of sound in air with temperature T=20.0 °C are: Velocity V=343.7 m/s, Frequency=500 Hz, and Wavelength=0.6874 m.
Therefore, distance of tag (ground water level) is expressed by:

$$D = V \times t$$

which “t” is the propagation time.

To calibrate dependencies on temperature which is mentioned above, a RFID tag connected to a temperature sensor has been selected to monitor temperature of the environment.

The system is based on the definite interval time to capture and transfer the data remotely. The system can be programmed and interval time can be changed according to the seasonal demands.

5.3 Data collection and transmission

At the allocated interval time the upper part of the piezometer triggers which sends RF waves to get radio frequency and ultrasound from LP. This data contains the proper information which is necessary to calculate water level according to the temperature. The GWL-box, figure 4, collects the information from transmitter. Then it firstly stores the collected data and transfers them to the main server using General Packet Radio Systems (GPRS) technology.

Figure 4: The GWL-box.

5.4 Data processing and warning

The prime location of devices, GWL-box, LP rainfall gauge, is identified with an unique ID. The GWL-box sends the collected data via GSM. When the data has been transferred to the main central computer, it can be recognised from the device data it was sent from. Special software has been written to calculate and correlate water levels and illustrate the water table and pore water pressures on real-time bases, graphically. The processed data is used for slope stability analysis and a factor of safety is calculated. Thereafter it is possible to predict what will happen in the next few hours and further potential dangers can be recognised in the pre-analyses of the slopes. While the factor of safety approaches one, a warning procedure is released. At this stage the results can be shown on a GIS map to recognize the slope failure location and the areas at risk. Then by means of the internet and GSM technology results are distributed, firstly to authorized people who are responsible for the area as well as the alert signals which are set up in the endangered area. The warning system has the ability to send text messages to provided mobile telephone numbers, and send email to local authorities in order to trigger the installed alarms.

6 Conclusions

This paper investigates the applications of RFID-based system integrated with, GSM, and sensor technologies to automate the task of landslides monitoring and early warning by means of acquire groundwater table and pore water pressure on a real time bases. This system can provide low-cost, low energy consumption and timely active groundwater information on the slope areas with greater accuracy by using RFID technology. Such intelligent systems permit real-time control, enabling actions to be taken which will save valuable time. This research is conducted to identify opportunities for applying advanced tracking and data storage technologies in landslides monitoring and early warnings and to develop a model that explores how these technologies can be used in landslide monitoring.

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Intensity, attenuation and building damage from the 27th May 2006 Yogyakarta earthquake

P. Widodo[1], H. H. Wijaya[2] & Sunarto[3]
[1]*Department of Civil Engineering, Islamic University of Indonesia, Indonesia*
[2]*Former Student of Earthquake Engineering Management Master Program, Indonesia*
[3]*Department of Geography, Gadjah Mada University, Indonesia*

Abstract

The 27th May 2006 Yogyakarta earthquake caused more than 5500 casualties and hundreds of thousands of non-engineered buildings collapsed. It is necessary to investigate the seismic intensity, ground acceleration and building damage index. Direct site investigations to collect the severity distribution of objects, humans and environments have been done. The result of the investigation shows that in general isoseismic lines are in-line with Opak fault, the proposed attenuation relationship for seismic intensity and horizontal ground accelerations are matching well with previous research results and the distribution of the building damage index has a similar pattern with isoseismic lines.
Keyword: seismic intensity, isoseismic lines, ground acceleration, attenuation, damage index.

1 Introduction

According to several sources (Walter et al. [24]; Tsuji et al. [23]), the focus of the 27th May 2006 Yogyakarta earthquake with M_w = 6.2 was at approximately 10 km depth and only 15 km away from Yogyakarta city. Elnashai et al. [7] and Tsuji et al. [23] stated that there are several versions of the location of the epicenter.

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110061

So far the investigations soon after the 27th May 2006 Yogyakarta earthquake have concentrated on the earthquake parameters such as earthquake magnitude, epicenter and focal mechanism by Walter et al. [24], ground motions by Elnashai et al. [7] and Widodo and Trianto [25], non-engineered building damage and its distribution by Boen [3], Gousheng et al. [9] and Miura et al. [14], effects of the soil condition on building damage by Kertapati and Marjiono [13], and post disaster damage assessment by using satellite image by Miura et al. [14]. It is necessary therefore to extend the research especially on the seismic intensity. The main aim of this paper is to present the seismic intensity, ground acceleration and the non-engineered building damage from the 27th May 2006 Yogyakarta earthquake.

2 The seismic intensity and its development

Since a few decades ago the seismic or earthquake intensity has been used by seismologists and engineers to describe the severity of the site under earthquake attack. The severity of the site is mainly described by the damage of the man-made structures and the damage of the environments (Trifunac and Brady [22]). The level of human response due to anxiety, or discomfort, response of any object due to external disturbance, damage in particular types of structure and damage of the environment are the usual parameters used in the survey.

The seismic intensity can be determined by using traditional techniques or human judgment such as the direct interviewing of respondents and site visits. Further development in determining the seismic intensity is achieved by using ground motion records (Devenport [4]; Miura et al. [14]). This is one of the developments of the technique/method in determining the scales. Freeman [8] presented further development of the seismic intensity, i.e by constructing the demand spectra.

3 Seismic intensity and peak ground acceleration relationship

In many countries, the availability of the ground motion records is still a big problem including Indonesia. Several Indonesian strong earthquakes such as the 26th December 2004 Sumatera earthquake (M_w = 9.2), the 18 March 2005 Nias (M_w = 8.5) earthquake and the 27th May 2006 Yogyakarta earthquake (M_w = 6.2) occurred without any significant ground motion records. Accordingly the site response (ground acceleration for example) can not be easily connected to the seismic intensity.

The simplest relationship model between site response Y and seismic intensity I_{mm} can be expressed in the equation (Trifunac and Brady [22]; Panza et al. [17])

$$Log\,Y = b_o + b_1 . I_{mm} \tag{1}$$

where b_o and b_1 are constants.

Several aspects will affect the seismic intensity including soil site condition. Dynamically, the soil site condition can be represented by the predominant period T_G of the soil layers. Accordingly, Kanai [10] proposed the mathematical model for the ground acceleration and seismic intensity relationship.

4 Seismic intensity attenuation

Variations of the level of the seismic intensity scale over the distance mean that the seismic energy was attenuated. Over the distance, the seismic energy spreads out in 3-dimensional directions. Accordingly the imparted seismic energy per unit volume of soil mass will rapidly be attenuated. The principle of seismic energy attenuation has been used in attenuations of peak ground acceleration, velocity, displacement, attenuation of Arias intensity as well as attenuation of seismic intensity.

Dowrick [6] and Szeliga et al. [19] proposed the seismic intensity attenuation model as described in the equation as follows:

$$I = a + bM + c.r + d\log r \tag{2}$$

where I is the seismic intensity, a, b, c and d respectively are the coefficients, M is the earthquake magnitude, r is the focal distance, and the second and third terms in Eq. (3) indicate the effect of earthquake magnitude and focal distance.

In addition, Dowrick [6] also incorporated the effect of the earthquake mechanism in the attenuation model by setting different coefficients. Sometimes the required data is not completely provided. Another attenuation model as used by Karim and Yamazaki [12] is presented in the equation

$$I = c_o + c.M + c_2.Ln(R + \Delta) \tag{3}$$

where c_o, c_1 and c_2 are coefficients, R is epicenter distance and Δ is a particular value.

In the case when the data are very limited as in this study, the use of simpler attenuation is required, an example of which was presented by Sutardjo et al. [21],

$$I_x = I_o.e^{-b.x} \tag{4}$$

where x is the distance (in km) from the center of the maximum isoseismic line, I_x is the intensity level at x km from the center of the isoseismic line, I_o is the maximum intensity level and b is the attenuation rate of the intensity.

5 The building damage and damage index

Damage in general terms can be defined as something broken physically, shapely and as a function of things and causes partially/mostly loss of its value. Researchers have tried to transfer qualitative meaning to the quantitative value with the so-called damage index, damage factor or damage ratio. Several quantitative concepts of damage index/factor/ratio have been proposed by researchers. An example of building damage index quantification was presented by Qiwen et al. [18].

6 Methods of research

6.1 Parameters, time and building types

The main parameters for determining the seismic intensity scales respectively are the human behavior during earthquake, the response of any objects and the damage of the structure and environment. The direct site surveys were carried out from March to September 2009 by Wijaya [26]. The building objects are mainly non-engineered buildings such as un-reinforced clay brick buildings, partially reinforced clay brick buildings and only a small amount of well reinforced clay brick buildings.

6.2 Instruments, respondents, data and method of analysis

Instruments for collecting site data are mainly maps, questionnaire sheets, interview question lists, electronic camera, GPS and amount of supporting utensils. The head of villages, the head of sub-villages and the particular persons who are able to give relatively accurate information were selected as respondents. The data were collected according to purposive sampling in 17 districts and from 294 respondents. The collected data were analyzed both qualitatively and quantitatively. Transferring the qualitative information to the seismic intensity scales was carried out qualitatively.

7 Results and discussion

7.1 Isoseismic lines, seismic energy and moment, soil liquefaction

The seismic intensity scales of the site were determined based on the results of the interviews and recorded data in which more than 290 data were collected from the site. After smoothing the results, the isoseismic lines of the 27th May Yogyakarta earthquake are presented in Fig. 1.

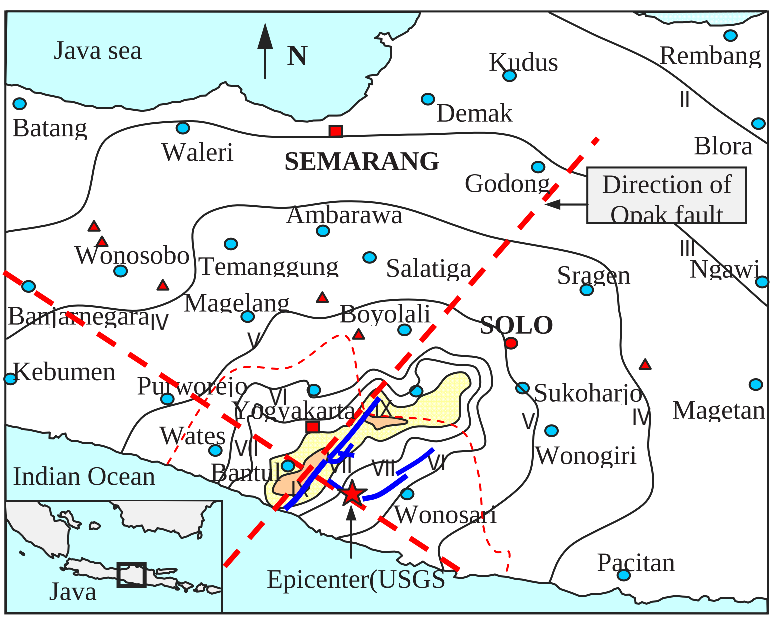

Figure 1: Isoseismic lines of the 27th May 2006 Yogyakarta earthquake.

It can be seen from the figure that the maximum seismic intensity is I_{mm} = IX. Similarly as presented elsewhere, the maximum seismic intensity does not always coincide with the location of the epicenter. It shows that the shape of the isoseismic lines is not nearly circular but tends to be similar to the isoseismic lines due to the Tonghai earthquake.

According to Sulaiman et al. [20] the seismic moment Mo of the 27th May 2006 earthquake is estimated to be equal to 8.1325.10^{25} dyne.cm with a rupture area of 200 km^2 (Walter et al. [24]). Plots of these earthquake parameters to the Kanamori [11] graph are presented in Fig. 2 and Fig. 3. They show that these parameters are matching well with the Kanamori [11] plot.

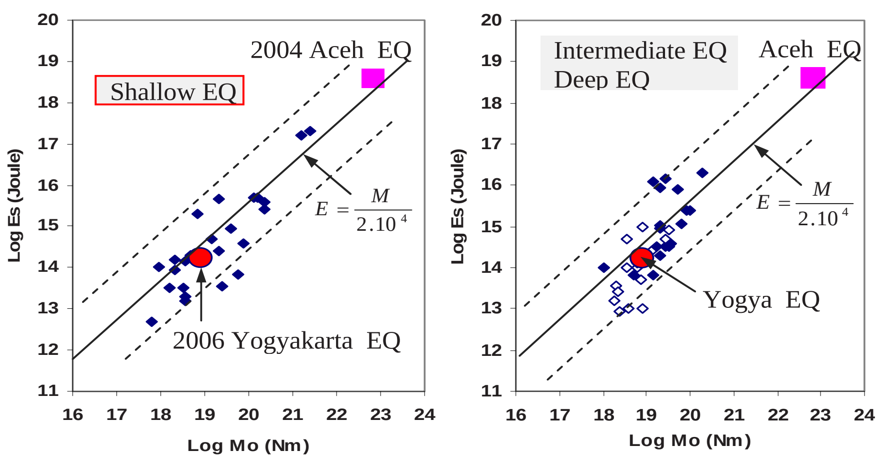

Figure 2: Energy and seismic moment of Yogyakarta EQ plot to Kanamori [11].

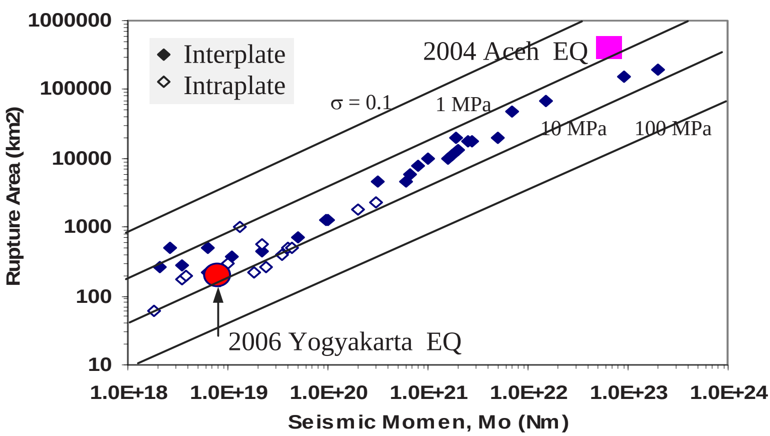

Figure 3: Energy and seismic moment of Yogyakarta EQ plot to Kanamori [11].

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Walter et al. [24] illustrated the cross section of soft sediment soil deposits from Merapi Mountain to Opak river/fault. According to Walter et al. [24] the depth of soft sediment may reach 200 m. Meanwhile Nurwidyanto et al. [16] found that the Opak fault is buried by soil sediment with the depth ranging approximately from 40 to 75 m. Eko et al. [5] studied potential liquefaction of the site. Their study revealed that the elevation ground water level is relatively high ranging from -0.60 to 4.0 m from the local ground surface. A plot of isoseismic lines into the Eko et al. [5] result is depicted in Fig. 4.

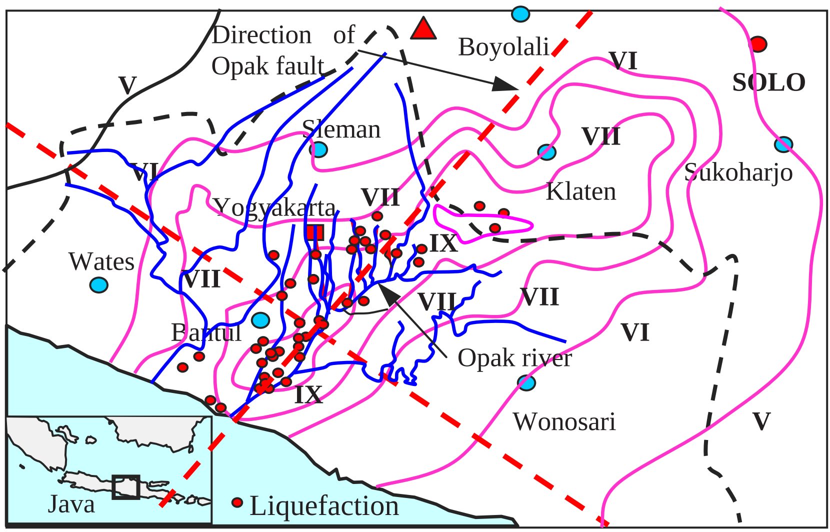

Figure 4: Liquefaction sites (Eko et al. [5]) plot to isoseismic lines.

It is clearly shown in Fig. 4 that the Opak fault is exactly in-line with the Opak river. It is shown in the figure that the liquefied soil mostly occurred at the ground with the seismic intensity I_{mm} = VIII and partly occurred at the region with I_{mm} = VII. This result confirms that of Anonym [1].

7.2 Seismic intensity attenuation

The result of the research presented in this paper is based only on the data collected from the 27th May 2006 Yogyakarta earthquake. Having limited data, the seismic intensity attenuation model based on Eq. (4) was used and the result is presented in Fig. 4. The attenuation is constructed based on data from all respondents. The attenuation is constructed in-line direction with the Opak fault as presented in Fig. 1 and can be expressed mathematically as follows:

$$I_{mm} = 8.889.e^{-0.0088.L} \tag{5}$$

where L is the distance from the center of isoseismic lines.

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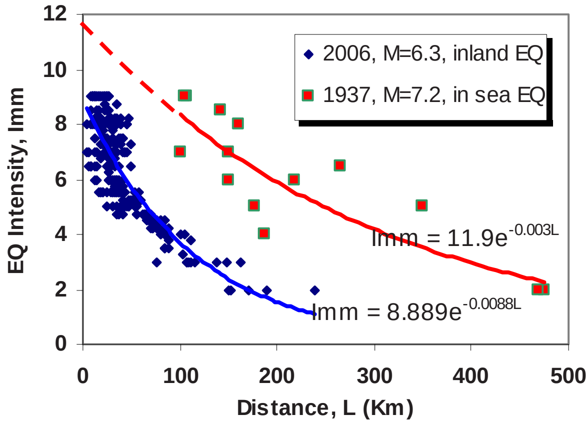

Figure 5: Modified mercalli intensity I_{mm} attenuation.

Fig. 5 is the comparison between two seismic intensity attenuations, i.e attenuation for seismic intensity of the 27th May 2006 and the 27th September 1937 Yogyakarta earthquake (Sutarjo et al. [21]). It is shown in the figure that land earthquakes attenuate faster than sea earthquakes. This result confirms the common theory which says that the shallow crustal earthquakes attenuate faster than the in-sea /subduction earthquakes.

7.3 Comparison with other seismic intensity attenuations

It is necessary to make a comparison of the seismic intensity attenuation as written in Eq. (6) with attenuation of other earthquakes.

The comparison between the 27th May 2006 seismic intensity attenuation and the Californian earthquake (Barosh [2]) is presented in Fig. 6. It can be identified that the proposed seismic intensity attenuation is well performed.

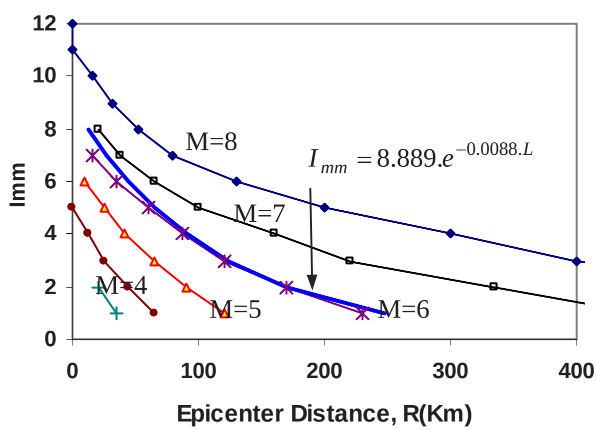

Figure 6: Comparison with other seismic intensity attenuations.

7.4 Ground acceleration attenuation

Elnashai et al. [7] conducted earthquake reconnaissance at the site and found only two records from two closer stations, i.e YOGI (Yogya) and BJI (Banjarnegara) at distances of 10 km and 90 km respectively from the epicenter.

According to Elnashai et al. [7], the most probable ground acceleration histories for the N-S components are 0.27 g (10 km from the epicenter) at YOGI station and 0.028 g (90 km from the epicenter) at BJI station. In addition, Elnashai et al. [7] also presented several possible ground acceleration attenuations that might be applied at the region. The interpolation of the applied attenuation gives the I_{mm}- ground acceleration relationship presented in Fig. 7 and is expressed mathematically in the following equation,

$$Log\ a_h = 0.2208.I_{mm} + 0.5446 \tag{6}$$

where a_h is the peak horizontal ground acceleration.

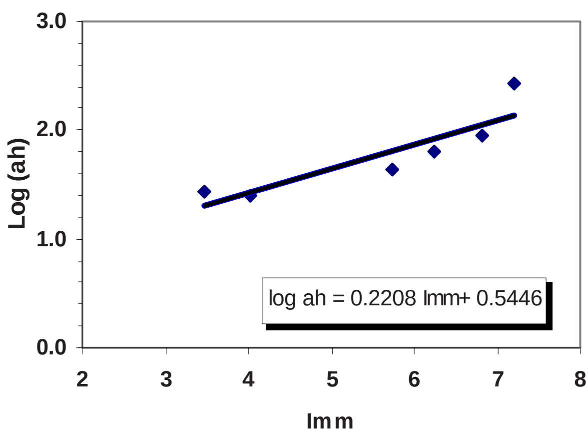

Figure 7: I_{mm}-Log a_h relationship.

The proposed peak horizontal ground acceleration attenuation can be developed by substituting Eq. (5) into Eq. (6) to yield (for M_w = 6.2)

$$Log\ a_h = 1.96.e^{-0.0088.L} + 0.544\ . \tag{7}$$

The comparison of the peak ground acceleration attenuation from Eq. (7) and several shallow crustal peak ground acceleration attenuations is presented in Fig. 8. It is shown in the figure that ground acceleration attenuations are widely variable, everything depends on the aspects that have been mentioned before. The proposed ground acceleration attenuation is very close to that of Campbell (1989) for a distance L > 20 km and very close to that of McGuire (1977) for a distance L < 20 km.

The comparison of the I_{mm}-ground acceleration relationship presented in Eq. (7) with several similar relationships is presented in Fig. 9. The figure shows that the relationship proposed by Coulter, Waldron and Devine (1973) and Medvedev and Sponheuer (1968) respectively fall in the upper bound and the lower values; the same as reported by Murphy and O'Brien [15]. The I_{mm}-ground acceleration relationship proposed by Hershberger (1956) is completely crossing with the proposed relationship result of this research/study. However, those proposed relationships still fall in the range of the upper and the lower bound values.

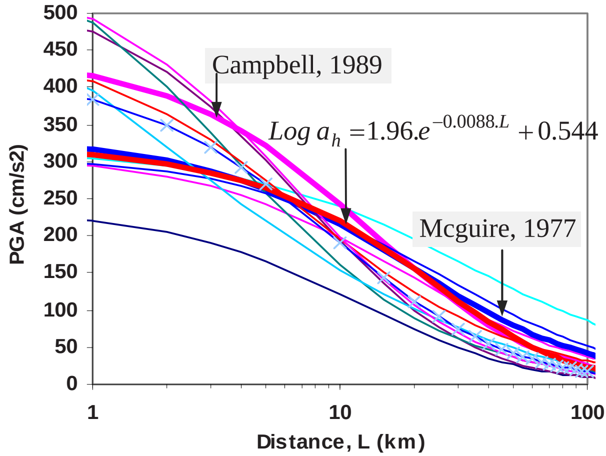

Figure 8: The comparison of ground acceleration attenuation.

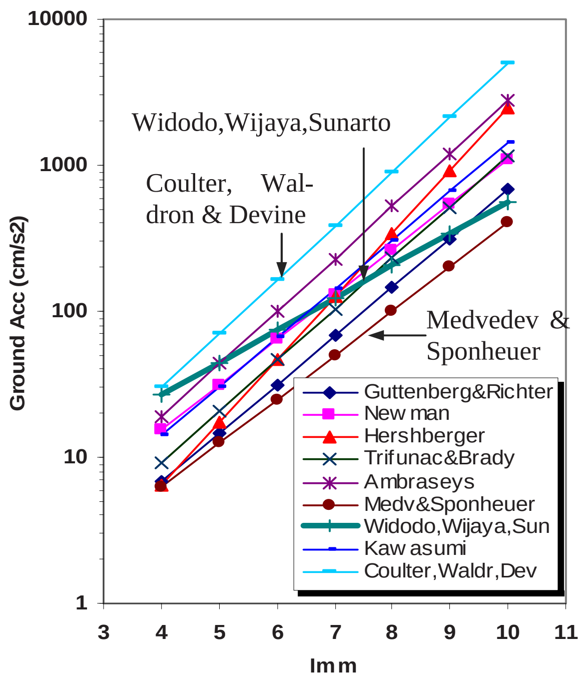

Figure 9: I_{mm}-ground acceleration comparison.

7.5 Damage index map

From a Civil Engineering point of view, the damage index is commonly used to describe the damage level of structural element, storey and whole structure quantitatively. The quantification of the damage can be determined from simple assessment of an object to a very complicated formulation. As shown in Table 1, Qiwen et al. [18] presented an estimation of damage index values at every damage category for dwellings. The damage descriptions are connected to damage state category.

Data concerning the descriptions of building damage have been collected during a direct site survey. These data have then been connected to the descriptions which are presented by Qiwen et al. [18]. Accordingly, the level of the damage index of the building at every site can be determined approximately. The result then is plotted in the map as presented in Fig. 10.

It can be seen from Fig. 10 that the shape of the damage index contours very closely resemble the isoseismic lines which are shown in Fig. 1. At the sites where the seismic intensity I_{mm} = IX most of the buildings were totally collapsed. This condition is associated with a damage index equal to 1. Most researchers agree that the buildings can still be repaired when the level of structural damage index less than 0.35-0.4.

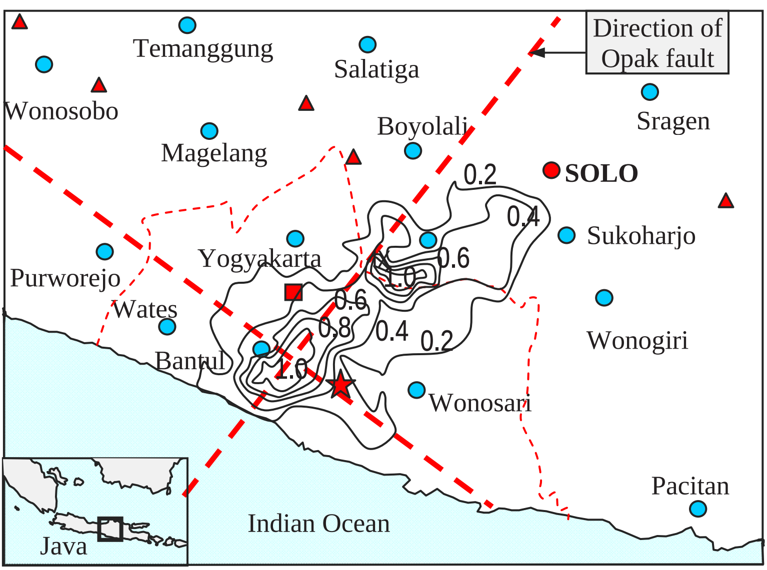

Figure 10: Damage index map.

8 Concluding remarks

The research/site investigation of the seismic intensity, the ground acceleration and the distribution of structural damage from the 27th May 2006 Yogyakarta earthquake has been carried out. Findings from the site and the analysis can be formulated as follows:

a. Isoseismic lines under the 27th May Yogyakarta earthquake in general are in-line with the direction of Opak fault and meet well with the soil liquefaction as reported by Eko et al. [5].
b. The proposed seismic intensity attenuation in general confirms well the similar attenuation which is proposed by researchers.
c. In addition, the simple proposed ground acceleration attenuation also conforms to the Campbell (1989) and McGuire (1977) attenuation.
d. Even though the I_{mm}-ground acceleration relationship is completely crossing with a similar relationship proposed by Hershberger (1956), in general it still falls in the range value.
e. The shape of the building damage indexes in general has a similar pattern to the seismic isoseismic lines.

Acknowledgements

Acknowledgements are addressed to the Biro Perencanaan Kerjasama Luar Negeri (BPKLN), Kementerian Pedidikan Nasional Republic of Indonesia for full financial support of this research.

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Disaster preparedness under the decentralization system of governance in Uganda

B. Sserwadda
Department of Social Work and Social Administration, Islamic University in Uganda, Uganda

Abstract

The study sought to determine the levels of disaster preparedness under decentralization among selected districts in Uganda. The districts targeted were 17 and the respondents were district disaster management personnel, in the office of the Chief Administrative Officer, local council members who are the legislators, district disaster management committees and representatives from the community. The results indicated that there is poor capacity on the part of staff in understanding the key standards that relate to disaster responsiveness. The personnel holding these portfolios are not well trained to handle emergency response. 89% of the districts covered had no facilities to evacuate the vulnerable in case of a disaster. However, planning is done at district level and this creates plans for emergencies that have localized dimensions. Resource utilization for disaster preparedness activities can be incorporated in the other plans using locally generated resources. The efforts to build the capacity of the district personnel as well as that of the community to understand the dynamics of disaster management should be done. In conclusion therefore, it should be noted that it is a human right for vulnerable and resource constrained communities and populations to be protected against problems brought about by disasters. By looking at the challenges associated with managing disasters, and by studying the opportunities presented by the decentralization system in Uganda, better options could be generated to establish a more sustainable mechanism to reduce the losses associated with disasters both in terms of human and other resources.
Keywords: disasters, preparedness, decentralisation, Uganda.

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110071

1 Introduction

Uganda is a landlocked country of fairly high elevation in East Africa with a total area of 236,040 square kilometers of which the land area is 199,710 and water makes up the remaining 36,330 square kilometers. At the lowest level, is Lake Albert, with an elevation of 621 meters above sea level, while at the highest, Mount Rwenzori, is at 5,110 meters. Uganda is an agricultural country of comfortable climate and good soils. The population is (2002 Census [1]) 24 million of which 51% is female and 49% is male. Most of the economic activity is geared to the production, handling and marketing of crops, livestock, wood and other products arising from these.

In Uganda natural disasters such as droughts, floods, landslides, windstorms and hailstorms contribute well over 70% of the disasters experienced and destroy annually an average of 800,000 hectares of crops making economic losses in excess of 120 billion shillings. Economic loses resulting from transport accidents and fires and other climate related disasters are estimated at shillings 50 billion annually (Uganda National Water development Report [2]).

1.1 Nature of disasters affecting Ugandan communities

The common disasters in Uganda are mainly water related (DWD [3]) The vulnerability of many Ugandan communities to water related disasters is growing by the day due to many undesirable human activities such as deforestation, ecosystem degradation, environmental pollution, social unrest, transport accidents, urban and wild fires and poor land use in many parts of the country.

The following are some of the major water related disasters and haw they affected their respective communities in terms of life and other material losses.

Basing on the statistics above, it shows that the opportunity cost for not being prepared for disasters is so high. It is therefore important that efforts to look out for opportunities to make communities more prepared for disasters are long overdue. The Ugandan context of decentralization therefore provides this opportunity.

1.2 Decentralization system of government

Decentralization is the practice of drawing power from the central government to the lower local governments (District & Sub-County). It is provided for in the Local Government Act 1997 [5] as well as the 1995 Constitution of Uganda [6]. Under decentralization, local authorities have more power over resources, more responsibilities and more decision-making autonomy. It is anticipated that the performance of local governments will be increasingly important for growth, poverty eradication and long-term rural development prospects. When it comes to disasters it is however not well documented whether the lower governments (District level) have the necessary capacity to mitigate the negative after effects of disasters let alone manage them. It is therefore imperative that efforts to equip

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the relevant departments with knowledge and skills not only to resourcefully plan but to also manage situations that may pose disasters.

Table 1: Water related disasters in Uganda.

Year	*Nature of Disaster*	*Impact*
1961/1962	El-Nino Rains	• Extensive floods experienced in many parts of the country; • Destruction of Roads, Bridges, houses, crops, and property worth millions of dollars (actual loss not established); • Drastic rise in the water level of Lake Victoria (by 2.5 M submerging all major infrastructures along the lake shores.
1993/94	Drought and Famine	Over 1.8 million people were affected due to lack of food, water, and inadequate pasture for livestock
1997/98	El-Nino Rains	• Landslides killed 53 people in total, and over 2,000 people were displaced. • Roads, Bridges, houses, crops, and property worth more than US$ 20 million were destroyed.
1999	Drought and Famine	Over 3.5 million people in 28 districts were affected by lack of food and a large number livestock suffered from inadequate pasture and water.

(Source: PEAP [4])

1.3 Projected solution

In order to have a meaningful intervention for the above, the following were identified as guiding objectives for the whole study.

1.3.1 Overall objective

To determine the levels of disaster preparedness under decentralization among selected districts in Uganda.

1.3.2 Specific objectives

1. To find out the capacity of staff in terms of knowledge and facilities in disaster preparedness and management at district level
2. To investigate the underlining opportunities at the districts in line with planning and resource utilization for disaster preparedness and management

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3. To create a sustainable mechanism of empowering district disaster preparedness personnel to plan and manage a holistic disaster management program.

2 Results

Due to resource constraints, only 17 districts out of the 25 most prone districts to disasters were considered in the study. This accounted for close to 68%. The following were realized after the study and shall act as the pillars for future planning to improve on local government capacities in disaster response and management.

2.1 District staff capacity in terms of knowledge

Data from the study indicated that there is poor capacity on the part of staff in understanding the key standards that pertain to disaster responsiveness. 75% of the districts had no staff specifically trained to handle disaster situations. Every human being has the right to life with dignity and respect for their human rights. Local governments have the responsibility to provide assistance in a manner that is consistent with human rights, including the right to participation, non-discrimination and information, as reflected in the body of international human rights. Due to the non professional mechanism that is employed to identify personnel in such sensitive departments, the personnel holding these portfolios are not trained to handle such responsibilities (Sphere Project – Humanitarian Charter and Minimum Standards [7]).

2.2 Facilities in disaster preparedness

In order to measure the capacity of districts in terms of capacity, the indicator that was used was one that looked at how the issue of vulnerability of disaster affected populations was handled. The groups most frequently at risk in disasters are women, children, older people, disabled people and people living with HIV/AIDS (PLWH/A). In certain contexts, people may also become vulnerable by reason of ethnic origin, religious or political affiliation, or displacement. It was identified that 89% of the districts covered had no facilities to evacuate the vulnerable in case of a disaster. This therefore means that causalities if a disaster struck could be in double figures. These facilities are critical in terms of both maintaining momentum in strengthening necessary institutionalized capabilities and in being able to measure the adequacy of preparedness capabilities and structures at local, national, regional and global levels (World Conference on Disaster Reduction [8]).

2.3 Opportunities at the districts

2.3.1 Planning

One of the major components that were decentralized to the lower governments was planning (Local Government Act 1997 [5]). The technical units following well set guidelines undertake planning with a strong degree of independence. The planned options are then passed on to the policy making organs which are the District councils of elected legislators who ratify the plans for implementation. Almost all the districts covered have utilized this opportunity to concisely come up with working options for the communities that they serve. It is this planning opportunity that the districts can use to plan for emergencies as well as disasters as each of these can have localized dimensions.

2.3.2 Resource utilization

Resource mobilization and utilization is one of the other components of decentralization. The districts following set guidelines have the mandate to utilize locally generated revenue and resources to implement the planned activities. The districts surveyed have utilized this as well. It is therefore a great opportunity to incorporate disaster preparedness activities using such resources because this type of revenue is unconditional.

2.3.3 Creating a sustainable mechanism of empowering district disaster preparedness personnel to plan and manage a holistic disaster management program

All the parties involved in the study at the local government levels agreed that it is very important that efforts to build the capacity of the district personnel as well as that of the community to understand the dynamics of disaster management is long over due. Special emphasis shall center on the following standards that need to be developed if a sustainable mechanism is to be put in place.

1) Participation of all parties technical, political and the effected populations,
2) Initial assessment by the technical teams,
3) Response modalities and logistics planning,
4) Targeting to measure levels of vulnerability of the affected populations,
5) Monitoring of the planned efforts
6) Evaluation of the intervention mechanisms,
7) Aid worker competencies and responsibilities and
8) Supervision, management and support of personnel.

3 Conclusions

In conclusion therefore, it should be noted that it is a human right for vulnerable and resource constrained communities and populations to be protected against problems brought about by disasters. By looking at the challenges associated with managing disasters, and by studying the opportunities presented by the Decentralization system in Uganda, better options could be generated to establish a more sustainable mechanism to reduce the losses associated with disasters both in terms of human and other resources. The local authorities that participated in the study were optimistic that if the findings could be put in practice, a new era in terms of protecting human life in the disaster prone areas shall be born.

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An overview of disaster management in India

A. J. Shah
Applied Mechanics Department, S V National Institute of Technology, Surat, Gujarat, India

Abstract

India is one of the hazard prone countries in South Asia. Floods, droughts, landslides, snowstorms, hurricanes and cyclones occur regularly. Among these earthquakes, floods and drought risk are extremely high. These hazards threaten millions of lives and cause large scale financial, infrastructure, agriculture and productivity losses that seriously hinder India's overall development. In India, as in the United States, the primary responsibility for responding to disaster lies at the state and the central level. The GOI have a national emergency plan for disaster management, some of the state also has a disaster management plan. It can be, and is called upon to assist when necessary, but there is a lack of awareness in the public. Many Indian States have limited resources and lack their own disaster management plans. Considering these problems, this paper attempts to throw light on a more integrated and responsive disaster management system in India. This paper will provide important information in three mutually reinforcing areas viz. disaster preparedness, response and rehabilitation management. The various case studies for disaster management will be discussed.

Keywords: disaster, mitigation, hazards, risk, safety management, India, Gujarat, Surat, Gir, students.

1 Introduction

1.1 What is disaster?

Disaster is a sudden, calamitous event bringing great damage, loss, and destruction and devastation to life and property. The damage caused by disasters is immeasurable and varies with the geographical location, climate and the type of earth surface/degree of vulnerability. This influences the mental, socio-

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110081

economic, political and cultural state of the affected area. Generally, disasters have the following effects in the concerned areas

i) It completely disrupts the normal day-to-day life.
ii) It negatively influences the emergency systems.
iii) Normal needs and processes like food, shelter, health, etc. are affected and deteriorate depending on the intensity and severity of the disaster.

It may also be termed as "a serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of the affected society to cope using its own resources."

Thus, a disaster may have the following main features:
Unpredictability, Unfamiliarity, Speed, Urgency, Uncertainty, and Threat.

Thus, in simple terms we can define disaster as a hazard causing heavy loss to life, property and livelihood, e.g. a cyclone killing 10,000 people, or a crop loss of one crop can be termed as disaster.

1.2 Types of disaster

Generally, disasters are of two types – natural and manmade. Based on the devastation, these are further classified into major/minor natural disaster and major/minor manmade disasters. Some of the disasters are listed in Table 1 below.

Table 1: Types of disaster.

Major natural disasters	Minor natural disasters
▪ Flood ▪ Cyclone ▪ Drought ▪ Earthquake	▪ Cold wave ▪ Thunderstorms ▪ Heat waves ▪ Mud slides ▪ Storm
Major manmade disaster	**Minor manmade disaster**
▪ Setting of fires ▪ Epidemic ▪ Deforestation ▪ Pollution due to prawn cultivation ▪ Chemical pollution. ▪ Wars	▪ Road / train accidents, riots ▪ Food poisoning ▪ Industrial disaster/ crisis ▪ Environmental pollution

1.3 Risk

Risk is a measure of the expected losses due to a hazardous event of a particular magnitude occurring in a given area over a specific time period. Risk is a function of the probability of particular occurrences and the losses each would cause. The level of risk depends on:

i) Nature of the hazard
ii) Vulnerability of the elements which are affected
iii) Economic value of those elements.

1.4 Vulnerability

It is defined as *"the extent to which a community, structure, service, and/or geographic area is likely to be damaged or disrupted by the impact of particular hazard, on account of their nature, construction and proximity to hazardous terrain or a disaster prone area"*

1.5 Hazards

Hazards are defined as *"Phenomena that pose a threat to people, structures, or economic assets and which may cause a disaster. They could be either manmade or naturally occurring in our environment."*

The extent of damage in a disaster depends on:

i) The impact, intensity and characteristics of the phenomenon and
ii) How people, environment and infrastructures are affected by that phenomenon.

This relationship can be written as an equation:

Disaster Risk = Hazard + Vulnerability

2 Overview of the Disaster Risk Management Programme

The Government of India (GOI), Ministry of Home Affairs (MHA) and United Nations Development Programme (UNDP) signed an agreement in August 2002 for the implementation of *"Disaster Risk Management"* Programme to reduce the vulnerability of the communities to natural disasters, in identified multi–hazard disaster prone areas.

Goal: "*Sustainable Reduction in Natural Disaster Risk*" *in some of the most hazard prone districts in selected states of India".*

The four main objectives of this programme are:

1. National capacity building support to the Ministry of Home Affairs.
2. Environment building, education, awareness programme and strengthening the capacity at all levels in natural disaster risk management and sustainable recovery.
3. Multi-hazard preparedness, response and mitigation plans for the programme at state, district, block and village/ward levels in select programme states and districts.
4. Networking knowledge on effective approaches, methods and tools for natural disaster risk management, developing and promoting policy frameworks.

2.1 Disaster management in India "Government of India" [1]

"*Ministry of Home Affairs*":

i) A review of the disaster management mechanism was carried out by the Government of India after the Bhuj earthquake. It was noted that there was need for building up holistic capabilities for disaster management – so as to be able to handle both natural and man-made disasters. It was accordingly decided that the subject of Disaster Management be transferred from the Ministry of Agriculture to the Ministry of Home Affairs (excluding drought and epidemics and those emergencies/disasters which were specifically allotted to other Ministries).

ii) India has been very vulnerable to natural hazards and calamities. The Bhuj earthquake accounted for 13,805 deaths, the super cyclone in Orissa accounted for 9,885 deaths. The Government are of the view that if appropriate mitigation measures had been taken these casualties could have been reduced significantly.

iii) Each year disasters also account for the loss of thousands of crops in terms of social and community assets. It is clear that development cannot be sustainable without building in mitigation into the planning process. Keeping the above factors in view, the Government of India have brought about a change in policy which emphasizes mitigation, prevention and preparedness. A strategic roadmap is prepared on the succeeding pages that has been drawn up for reducing the country's vulnerability to disasters. Action for reducing our vulnerabilities to disasters shall be taken in accordance with the roadmap. The roadmap will be reviewed every two years to see if any change in direction is necessary.

A Disaster Management Plan in India includes the following:-

- Institutional and policy framework;
- Early warning system;
- Disaster prevention and mitigation;
- Preparedness.

2.1.1 Institutional and policy framework

- The institutional and policy mechanisms for carrying out response, relief and rehabilitation have been well-established since Independence. These mechanisms have proved to be robust and effective insofar as response, relief and rehabilitation are concerned.
- At the national level, the Ministry of Home Affairs is the nodal Ministry for all matters concerning disaster management.
- National Crisis Management Committee (NCMC).
- Crisis Management Group.
- Control Room (Emergency Operation Room).
- Contingency Action Plan.
- State Relief Manuals Funding mechanisms.

2.1.2 Early Warning System

- Cyclone.
- Indian Meteorological Department (IMD) is mandated to monitor and give warnings regarding Tropical Cyclone (TC). Monitoring process has been revolutionized by the advent of remote sensing techniques. A TC intensity analysis and forecast scheme has been worked out using satellite image interpretation techniques which facilitate forecasting of storm surges.
- The meteorological satellite has made a tremendous impact on the analysis of cyclones. INSAT data has also been used to study the structures of different TCs in the Bay of Bengal. IMD is also producing Cloud Motion Vectors (CMVs). Very High Resolution Radiometer (VHRR) payload onboard INSAT –2E which have been improved upon to provide water vapour channel data in addition to VIS and IR onboard INSAT – 2E. A separate payload known as Charged Couple Device (CCD) has also been deployed onboard this satellite.
- Flood.

At present there are 166 flood forecasting stations on various rivers in the country which includes 134 level forecasting and 32 inflow forecasting stations, river-wise break up. The flood forecasting involves the following four main activities:

i) Observation and collection of hydrological and hydro-meteorological data.
ii) Transmission of data to forecasting centres.
iii) Analysis of data and formulation of forecast.
iv) Dissemination of forecast.

For other natural disasters specific early warning systems are under progress.

2.1.3 Disaster prevention and mitigation

The Government of India have adopted mitigation and prevention as essential components of their development strategy. The Tenth Five Year Plan document has a detailed chapter on Disaster Management.

The Government of India have issued guidelines that where there is a shelf of projects, projects addressing mitigation will be given a priority. Measures for flood mitigation were taken from 1950 onwards. As against the total of 40 million hectares prone to floods, an area of about 15 million hectares has been protected by construction of embankments.

A National Core Group for Earthquake Mitigation has been constituted consisting of experts in earthquake engineering and administrators.

A Disaster Risk Management Programme has been taken up with the assistance from UNDP, USAID and European Union in 169 most hazard prone districts in 17 States including all the 8 North Eastern States.

Under this programme disaster management plans have been prepared for about 3500 villages, 250 Gram Panchayat, 60 blocks and 15 districts.

2.1.4 Preparedness

Mitigation and preparedness measures go hand-in-hand for vulnerability reduction and rapid professional response to disasters.

The Central Government is now in the process of training and equipping 96 specialist search and rescue teams, each team consisting of 45 personnel including doctors, paramedics, structural engineers, etc.

A 200 bedded mobile hospital, fully trained and equipped is being set up by the Ministry of Health and attached to a leading Government hospital in Delhi. The Geographical Information System (GIS) data base is an effective tool for emergency responders to access information in terms of crucial parameters for the disaster affected areas.

2.2 Gujarat State Disaster Management Policy (GSDMP)

The Gujarat State Disaster Management Policy [2] considers the understanding of hazards and disasters, their behavior, and the risks they pose to the community as fundamental to achieving successful disaster management. Thus, the strategy for implementing the GSDMP emphasises an integrated approach to disaster management, covering the following phases of managing disasters as essential components of any disaster management program: Pre, Impact and Post disaster phase.

In order to carry out the prescribed activities contained within this policy, the GoG has defined a framework of operation for a set of agencies that play a key role in disaster management. The GSDMP envisages a DM framework where the following entities play significant roles:

- Gujarat State Disaster Management Authority.
- State Relief Commissioner.
- Government departments.
- District Administration, headed by the District Collector.
- Local Authorities, including Municipal Corporations, District, Talukas, Gram Panchayats etc.
- Voluntary agencies, including NGOs.
- Public sector, private sector; community.

The implementation framework is based on the premise that disaster management is not a separate sector or discipline but an approach to solving problems that facilitates disaster management, harnessing the skills and resources across stakeholders. Therefore, a key element of the policy framework is to leverage the resources and capability of existing entities and build new capabilities, wherever necessary. While for most activities, the implementation agencies remain the local authorities and Government functionaries, at the state level, GSDMA provides the overall direction and guidance that keeps the focus of various entities on disaster management.

2.3 Mumbai (Metro Polyton City), India Disaster Risk Management profile

Functional arrangements. Consistent with the national approach, Mumbai's Disaster Management Plan [3] refers to its goals of mitigation strategy as:

- To substantially increase public awareness of disaster risk so that the public demands safer communities in which to live and work.
- To significantly reduce the risks of loss of life, injuries, economic costs, and destruction of natural and cultural resources that result from disasters.
- Inter-City Linkages.
- Land Use Management.

2.3.1 Vulnerability issues

- Fire and industrial accidents have been part of the landscape of the city.
- Floods. Mumbai DMP identifies 10 sections along the Central Railway.
- Chemical (transport, handling), biological, and nuclear hazards.
- Earthquakes. Mumbai lies in the Bureau of Indian Standards (BIS) in Seismic Zone III.

3 Case studies and conclusion derived

3.1 Management of earthquake

India high earthquake risk and vulnerability is evident from the fact that about 59 per cent of India's land area could face moderate to severe earthquakes. During the period 2000 to 2010, more than 25000 lives were lost due to major earthquakes in India, which also caused enormous damage to property and public infrastructure. All these earthquakes established that major casualties were caused primarily due to the collapse of buildings.

These emphasise the need for strict compliance of town planning bye-laws and earthquake resistance building codes in India. These guidelines have been prepared taking into account an analysis of critical gapes responsible for specific risk.

These guidelines emphasise the need for carrying out the structural safety audit of existing lifelines structures and other critical structures in earthquake prone areas, and carrying out selective seismic strengthening and retrofitting.

The earthquake guidelines rest on the following six pillars of seismic safety for improving the effectiveness of earthquakes management in India.

The following are the 6 pillars:

- Earthquake resistant construction of new structures.
- Selective seismic strengthening and retrofitting of existing priority structures and lifeline structures.
- Regulation and enforcement.
- Awareness and preparedness.
- Capacity development of education, training, R & D, capacity building and documentation.
- Emergency response.

3.2 Surat, Disaster Management Plan

The city of Surat situated in the State of Gujarat in India having population of more than 4.7 million.
Plague in Surat:

The plague became an issue of global concern. Close to 200 deaths were linked to the outbreak in Surat. The disease created widespread panic and led to a mass exodus from the city. Apart from the human tragedy, it was a severe blow to not only Surat's economy which suffered a loss of several million rupees every day, but also to the nation's economy. The outbreak had an impact on industrial production, tourism, export, and many other areas. International flights to India were temporarily suspended, and export of food grains from Surat was banned. The precipitating factor for the outbreak of plague in Surat was constant rain which lashed the city for more than two months, and led to flooding and large-scale water-logging in low-lying areas. The primary reason for this was the faulty drainage system. Hundreds of cattle and other animals died due to the flood and water-logging. The floods, in fact, only brought to a crisis point the dangers inherent in inadequate waste management systems.

Conclusion: This plague taught a lesson to the Municipal Authority, other related authorities and the general public in the city. Following the plague all the drainage systems and storm water system were improved. Systems were built for the solid waste management and cleanliness. The public became aware about the issues of cleanliness.

The flood management system was introduced; a hydrological contour map was prepared for the city. Rescue and relief services are put in order.

3.3 The Bhopal gas tragedy

The careless siting of industry and relatively poor regulatory controls leads to ill-health in the urban centers. The Bhopal gas tragedy on December 2nd, 1984, where Union Carbide's plant leaked 43 tons of methyl isocyanate and other substances, used in the manufacture of pesticides, is one of the worst industrial accidents in the recent past. Of the 520,000 people who were exposed to the gas, 8,000 died during the first week and another 8,000 later. The impact on the survivors is visible even today.

Conclusion: The government of India and respective state government through their pollution control board have laid down strict regulation and monitoring system for industries to avoid any such accident. Every industry is forced to have the safety measures and disaster management plan.

3.4 Disaster management plan for GIR: a case study [4]

Conservation values:

- Largest compact track of dry deciduous forest in the semi-arid western parts of the country.
- Rich biodiversity area supporting large number of species including several endangered species.

- Highest concentration of top carnivores-lions and leopards (over 600), and possibly the single largest population of marsh crocodiles in the country.
- Important biological research area with considerable scientific, educational, aesthetic and recreational values.
- Mother of cultural and religious evolution in Saurastra.

During 2001 to 2006 there were about 150 incident of fire affecting small, medium and large areas. More than 70 lions died between 2001 and 2006.

Table 2: Present situation of GIR Disaster Management.

Various disasters in park/ their action	*Preparedness*	*Mitigation*	*Prevention*
Forest fires	**Recommended:** Taking advantage of response to boost a "Preparedness culture". RS and GIS is used	**Yes,** fire fighting, fire line maintained, local participation	Low Priority (only when the risk is imminent and no preventive multiannual programme had been launched on time)
Drought	**No,** no per meant water harvesting structures	**Yes,** water holes creation, Transport of water to wildlife	**No**
Epidemics	**No,** not any special mentions in existing management plan	**Yes,** Vaccination, cattle prevention	**No**
	No special work regarding this		

National Disaster Management Centre (Sasan)

- Information management
- Preparation of strategies, policies and plans
- Assessing vulnerability
- Coordination and support during disaster and emergency situations
- Non-emergency situations
- Conducting audits
- Training and community awareness.

3.5 India tsunami [5]

3.5.1 Magnitude of disaster

On December 26, 2004 the tsunami caused extensive damage in 897 villages in five states/UTs in India. During the tsunami 4,259 were Injured, 5,555 people were missing and 10,749 were dead. The major sectors affected in each state: fisheries and boats, ports and jetties, roads and bridges, power and ICT, housing, water supply and sewerage and social infrastructure.

Rescue and relief operations were adjusted to be speedy, effective and timely by the external agency i.e. undertaking debris removal and disposal of bodies, dispatching relief material, providing food, water, and medical assistance. Adopting good past practices:

- Earlier disaster management programs, done successfully, were revisited to carry forward the lessons learned.
- Encourage ownership of solutions by potential beneficiaries to ensure sustainability.
- Encourage partnerships of government, beneficiaries, community-based women's organizations and NGOs to ensure sustainable development.
- Demonstrate that project implementation can be assured through a fully empowered Project Management Unit with competent leadership.
- Address need for a long term approach to O&M funding.

3.6 Role of engineering student for disaster management

A lot of the nation's older teenagers are part of 'emergency rescue teams' – mostly the training goes side by side along with 'compulsory military training' programs. I would like to negate student community from search and rescue since that is a highly specialized job and should be left to professionals. The basic role of the student, in my opinion, is AWARENESS of what to do during and after disasters. This would lessen panicking, paranoid and uncontrollable people running around. Also, knowing what to do when disaster strikes will also lessen the death toll. Knowing what to do after a disaster, and at least basic first aid, will enable students to help the authorities in saving lives. If students are well trained then if there is a disaster they are able to protect themselves and they can also help others. The student branch is the most well informed branch of the community. They can spread awareness about disaster management. In addition, they can form association to help in times of disaster. Children can help in managing disasters in many ways, and students can help in rehabilitation and resettlement of victims.

- They can spread awareness through rallies in streets.
- Volunteer in the information centers and form associations for the Disaster-Day.
- Provide the victims with basic needs.
- Preventing disasters at home – stopping building fires due to petty reasons like a short circuit.

4 Conclusion

Disasters are inevitable. The fact lies in stating "*we must all be prepared to try to survive the current and the forthcoming disasters*." We cannot rule the nature but we can at least be watchful and vigilant. The structured and preplanned preparedness and the healthy response to the disaster will help save the lives. Our success lies in, as is preached by the great people that existed and exist on earth "*unity and unanimity devoid of discords*."

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Section 2
Emergency preparedness

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A decision support framework for large scale emergency response

D. T. Wilson, G. I. Hawe, G. Coates & R. S. Crouch
School of Engineering and Computing Sciences,
University of Durham, UK

Abstract

Coordination is often cited as one of the principal problems in large scale emergency response. By representing the problem mathematically, a decision support framework capable of viewing the 'big picture' in emergency response, and processing it effectively and efficiently, has been developed. This will result in a provision of high quality suggestions for coordinated response operations, which can be called upon during the decision-making process. In order to ensure the framework is relevant and applicable, significant modeling challenges must be overcome to translate a highly uncertain environment incorporating a complex network of interdependencies into a rigorous mathematical formulation.
Keywords: decision support, mathematical modelling, optimisation, terrorism.

1 Introduction

Following recent high profile and unprecedented large scale emergencies such as the terrorist attacks of September 11th 2001 in USA, or of July 7th 2005 in London, questions relating to how an emergency response operation to such an event should be carried out have gained considerable exposure. Response operations at present are predominantly defined through pre-planned standard operating procedures which, while working well when applied to familiar or foreseeable situations, may not provide the required level of flexibility to ensure a high quality response to unprecedented events.

The provision of a decision support framework, capable of constructing a mathematical model which represents a real-time response operation and applying optimization techniques to find potential solutions, could contribute to ensuring a flexible and robust response strategy. This paper discusses progress made on

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110091

the development of such a decision support framework. In Section 2, a selection of key examples of similar work is discussed. Following this, in Section 3 we present the proposed decision support framework at a high level. In Section 4, a case study example will be defined. Details will then be given on the building of a mathematical model of this example in Section 5, before key results are presented in Section 6. Finally, conclusions and further work are discussed in Section 7.

2 Related work

We proceed to briefly review decision support frameworks developed to address response to large scale emergencies, particularly those which feature an optimization model at their center. Firstly, we shall review research which approaches the large scale emergency response problem from the angle of logistics, including those which explicitly incorporate the transportation of casualties in their models. Secondly, we will describe work which addresses the problem in question though a model of resource allocation and task scheduling.

2.1 Logistical formulations

A popular view of the problems presented by large scale emergency response involves consideration of the logistical issues. In particular, it is proposed that response operations could be improved significantly by focussing on the distribution of consumable resources, such as medical supplies, around the emergency environment. These approaches can then build upon the extensive amount of previous research into general vehicle routing and network flow problems.

A decision support model presented in [1] tackles the problem of transporting several different commodities over a network via several possible modes of transport from supply points to demand points. The result of the model is a detailed description of how the available vehicles should move over the transportation network over time along with specifications of the flow of each type of commodity. An approach to a similar problem is presented in [2]. Attempting to incorporate the uncertainty present in real response problems, the model is designed to be used immediately after an earthquake has struck, when information on the epicenter and magnitude has been received but details of actual impact are still uncertain. Decision support is delivered in stages, with the model updating the proposed solution as more information becomes available.

In [3], a model is presented for the inner city transportation of commodities using several modes of transportation following a disaster. The model allows vehicles to be called on from every point in the network, and so can replicate the use of civilian vehicles. Furthermore, it has been designed to facilitate re-planning so as to be of use in the rapidly changing environment of disaster response.

During any urban disaster there will be large numbers of injured civilians that need to be relocated. There has been some effort to incorporate both the transportation of commodities and the collection of casualties into the same model.

In [4] it is noted that helicopters can be used in disaster response operations to both deliver supplies and to transfer the wounded to hospitals, often combining the two tasks into one trip. The model presented is divided into two sub-models, separating tactical and operational decisions. The resulting sub-models present two separate, conflicting objectives (maximizing cost-efficiency for tactical decisions and minimizing total time for operational), with the authors presenting an iterative method for linking the two together.

2.2 Allocation and scheduling formulations

We now examine research which views the problems of interest as some form of *allocation* or *scheduling* problem. [5] provides an example of such work. Here, the authors consider a problem involving the allocation of personnel and equipment to operational areas after an earthquake has struck. The authors identify different types of operational area depending on the type of work that is to be carried out in them, for example search and rescue or stabilization work. The model also accepts as input the survival rates for trapped victims and for casualties who have been rescued but are awaiting treatment. The output of the model consists of a work schedule for all resources which will minimize the expected number of fatalities.

The problem of ambulance dispatch and reallocation during large scale emergency response is tackled in [6]. The authors present the notion of casualty 'clusters', suggesting that following a disaster there will be areas with high concentrations of casualties and by dispatching ambulances to these clusters as opposed to individual casualties located far away from any other, a higher level of efficiency will be achieved since ambulances will be able to fill their capacity quickly in each trip. By considering only casualty clusters, the allocation model is significantly reduced in size and is therefore easier to solve in a timely manner.

In [7] a problem of allocating personnel is also addressed, although in this case the units are engineering battalions and the tasks consist of repair work to be carried out following an earthquake. Here the authors decompose the overall problem into two stages, namely assigning a set of tasks to each unit and then describing how each unit should employ its resources to complete the work it has been assigned. The authors note that 'excessive logistical details' are omitted since the model is designed for use on a national scale and therefore details like transportation networks are of limited benefit.

2.3 Summary

We have highlighted some common approaches in designing decision support models for use in disaster relief. Various features of the general problem have been noted, from the stochastic nature of demand, through the need for emergency vehicles to re-fuel, to the flexible use of vehicles found in real disaster response situations. The encouraging results presented in the literature suggest that the application of mathematical modeling and optimization to the problems presented in large scale emergency response is worthy of further exploration. However, in such work it is common for assumptions to be made, some of which may not be appropriate. In [8], the author notes several assumptions commonly made by both practitioners and researchers in the disaster response domain and argues they are invalid. The author concludes that further research in the area could contribute through a more comprehensive modeling approach as opposed to the development of new solution algorithms. Through close collaboration with emergency planning practitioners we can take the opportunity to go some way in this direction. A comprehensive decision support framework with minimal assumptions and more detail can be developed, ensuring those details incorporated are the most pertinent to the problem domain.

3 Decision support framework

A high level overview of the proposed decision support framework is illustrated in Figure 1. It shows the general decision-making process, starting with the gathering of information prior to the event. Following initial information regarding the event, a rule-base may be used to formulate an initial response designed to meet established objectives. An iterative process is then undertaken, comprising of setting objectives, building or updating a mathematical model, and applying solution algorithms to solve it.

4 Problem definition

What follows is a description of a particular large scale emergency, and the characteristics of an associated response, currently being used as a case study for this research. Based on the terrorist attacks in London on July the 7th 2005, the problem describes a scenario involving multiple bombings in crowded areas within an urban environment. We describe in turn three aspects of the problem, namely the environment in which the event takes place, the resources used in the response, and the tasks which are assigned to these resources.

4.1 Environment

A map of London highlighting five disaster scenes, seven hospitals and six fire stations is displayed in Figure 2.

For the purpose of this case study, hospitals may be characterized by two factors, their location and their capacity (in terms of number of available beds). The hospitals shown on the map were used in the actual response to the London bombings - in particular, they were used by the London Ambulance Service – and it is these which will be considered in our mathematical model. The number of casualties taken to each hospital ranged from 6 (Chelsea & Westminster) to 208 (Royal London). In relation to the distribution of casualties during the actual event, the London Assembly report [9] states that “Dispersal of patients to hospitals was uneven because of breakdown in communications within the Ambulance Service.

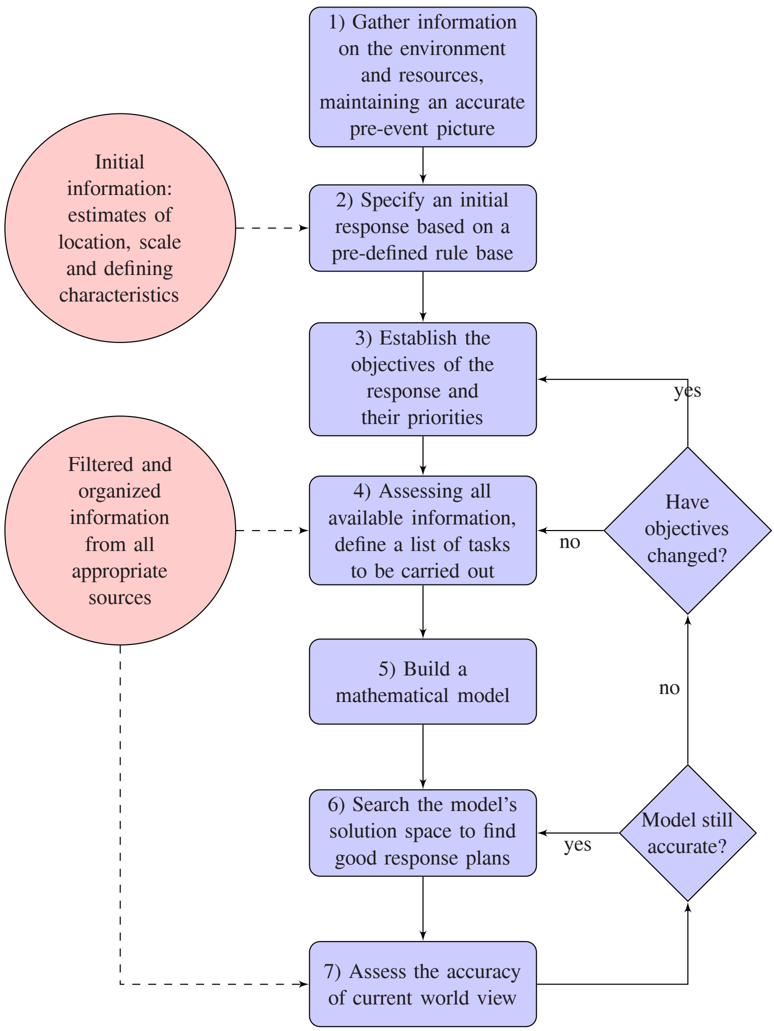

Figure 1: The decision support framework.

In the event, this had minimal impact on patients on 7 July" As such, we may set the capacities of hospitals to be relatively generous in relation to the number of casualties. Specifically, each hospital capacity will equal twenty percent of the total number of casualties under consideration.

The road network of central London may be modeled mathematically as a graph. Nodes of the road network graph represent junctions and points of interest such as hospitals, disaster scenes and fire stations. The edges joining these nodes represent roads, and as such may be described by their distance. Given this graph and the information associated with it, it is then possible to describe routes to be taken by emergency responders and to compute estimates of the resulting travel time.

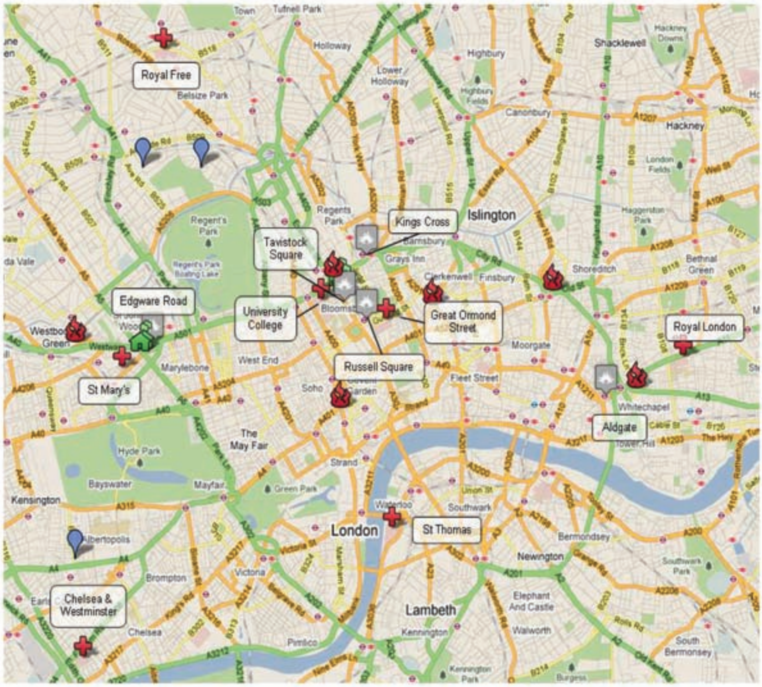

Figure 2: A map of the July 7th bombings. Disaster scenes and hospitals are labeled, while fire stations are denoted by a fire symbol.

Each of the five disaster scenes (Edgeware Road, Tavistock Square, Kings Cross, Russell Square and Aldgate) are described by three parameters: the number of casualties; the severity of injuries; and the stability of the scene. The severity parameter is used to define the distribution of initial health states amongst the casualties at the scene. The parameter will take a value between zero and one, with one corresponding to the most severe scene. The stability parameter is used to define the probability of each casualty being in some way trapped, and so requiring a fire-fighter unit to free them.

Casualties may be described by three parameters - their location, their health and their mobility (i.e. whether they are trapped in some way, and if so to what extent). The health of a casualty is denoted by a discrete classification, namely:

1. treatment may be delayed,
2. treatment is required urgently,
3. treatment is required immediately, and
4. casualty is either dead or death is imminent.

These are the four classifications assigned to casualties during triage [10]. Following the assignment of a health state to a casualty, we expect this health state to change as time passes. How their health changes can depend on what kind of environment the casualty is in (for example trapped under rubble, in a casualty clearing station or in an ambulance) as well as interventions by medical personnel. Predicting how the health of a casualty is likely to change over the course of a response operation is key to the effective evaluation of proposed response plans.

4.2 Resources

We may think of resources as being divided into four categories - personnel, vehicles, equipment and consumables. In the case of the July 7th bombings, four main groups provided resources to assist with the response operation, namely the health service, the police, the fire and rescue service, and volunteers (both organized and spontaneous). For the purpose of the problem being modeled, we shall focus our attention on the health service and the fire and rescue service.

A key component to the health service response is provided by the Ambulance Service, who provided several types of resources to the response operation of the London bombings. Paramedics represent the backbone of any health service response to a major incident, able to drive ambulances and to administer care to wounded civilians. The training of paramedics and their resulting capabilities can vary - in particular, some paramedics may have received Hazardous Response Team (HART) training in how to operate in an urban search and rescue environment. This particular distinction in abilities is included in our model.

In order to transport casualties from a disaster scene to a hospital, vehicles are required. A two-person paramedic team will have access to an ambulance, capable of carrying one casualty at any one time. For the purpose of this model, we assume that the link between a paramedic and their mode of transport is constant throughout the response operation.

In the scenario under consideration we do not consider the possibility of fires, and so the principle role of the Fire and Rescue service is in the extraction of casualties from within the inner cordon. We consider fire-fighters as being grouped into teams, and that these groupings remain constant over the course of operations. Each fire-fighter team has access to a fire engine vehicle for transportation to disaster scenes, which also carries the equipment necessary for rescue operations.

4.3 Tasks

Large scale emergency response operations may be broken down into a set of individual tasks which can be assigned to resources. In some cases, tasks may need further specification in terms of *how* the resource should go about completing it. These decisions can often be left to the individual resource agents. However, where these decisions may impact the overall response operation, it may be appropriate to make them at the higher level to ensure coordination. Tasks may be divided into two categories, essential and optional. Essential tasks must appear somewhere in some resources schedule in order for the solution to be considered valid.

In the case study under consideration, we consider it essential that each casualty be taken to a hospital. In order for this to happen, each casualty must be taken from the disaster scene to a designated casualty clearing station. If a casualty is trapped under debris of some kind a *rescue* task is required in order to achieve this. This task may only be performed by a team of fire fighters, and has no pre-requisite for completion. The duration of this task depends on the level of mobility of the casualty in question.

Once a casualty has been rescued, they will join all other casualties at the designated casualty clearing station. From here, each casualty must be transported to an appropriate hospital by a team of paramedics using an ambulance. The duration of this task is dependant on the choice of hospital, given which we calculate the distance of the shortest path and from this estimate the travel time. The decision of which hospital each casualty is to be sent to is necessary at this stage to ensure an effective distribution.

In addition to transporting casualties to hospitals, paramedics may deliver treatment on-scene. This may not always be an optimal course of action and so it is not required to be carried out for every casualty. The duration of the treatment will vary depending on the specific details of the injuries in question. Treatment may be carried out by any paramedic when the casualty is in the casualty clearing station. In addition, paramedics who have received HART training in operating in an urban search and rescue environment may administer treatment to casualties trapped in the inner cordon area who are awaiting rescue by the Fire Service.

5 Mathematical model

An initial mathematical representation of the case study problem is presented in this section. We propose to modify and build upon this initial model over the course of the research project, incorporating more features with each iteration. Combined with regular input and feedback from practitioners, this approach will ensure the end result is as applicable and relevant as possible.

5.1 The solution space

The concept of a solution space is fundamental to the design of a mathematical model. In the context of large scale emergency response, we require a solution to specify how the available resources should be distributed over time and space. Considering the tasks discussed in Section 4.3, we note that one type of task requires further specification when defining a solution – for each hospital trip, we may change which hospital the casualty must be taken to. Given a set of these tasks to be completed, we define a solution to be a set of *schedules*, one for each resource r_i available, of completely specified tasks Thus, a solution may be partially represented in the form shown in Figure 3.

Combining the above schedules with full specifications for each task defines a solution to the mathematical model. When evaluating a solution of the proposed form the times each task starts and finishes must be known in order to assess the expected outcome of a given solution. We can avoid the incorporation of these times into the solution itself, however, by making the assumption that all resources

Resource	Tasks
r_1	t_1, t_6, t_{13}
r_2	t_3, t_{10}, t_5, t_7
$\vdots$	$\vdots$
r_n	t_{11}, t_2

Figure 3: A solution schedule.

will begin work on their next task as soon as possible when taking into account any dependency which exists between tasks. That is to say, given a set of schedules in the form shown above, the start and finish times of each task can be deduced directly. Furthermore, this approach accounts for any variation in the duration of tasks.

5.2 Solution algorithms

Having defined a solution space, we require a method to search for solutions of high quality. For the purpose of this case study, a random local search algorithm was implemented. Given a specific solution $\hat{s}$, this algorithm proceeds to examine each solution in the *neighborhood* (see Section 5.3 below) in a random order. When a solution s with an improved objective value is found, the algorithm moves to this new solution. The process is repeated until an appropriate stopping criteria is reached.

5.3 The neighborhood structure

Given the above definition of a solution, we must now define a neighborhood structure. This structure helps define how a search algorithm explores the solution space, and is therefore highly influential on any search algorithm's performance. In our initial model we allow two types of neighborhood operations:

1. Moving a task around the schedules,
2. Changing the hospital a casualty is to be taken to.

For example, the algorithm could move from solution s_1 to solution s_2 as illustrated in Figure 4. Since solution s_1 can be converted into s_2 in only one operation, s_1 and s_2 are defined here as neighbors.

5.4 The objective function

Now that we have defined a solution space and specified how a local search algorithm can explore it, we must consider how to evaluate each solution found. Firstly, the start and end times of each task are extracted from the solution. Given these times, the objective function computes a measure of the number of expected fatalities. We wish to model the effect different parts of the disaster environment

$$
\begin{array}{llcll}
 & s_1 & & & s_2 \\
r_1: & t_4, t_1 & & r_1: & \mathbf{t_2}, t_4, t_1 \\
r_2: & t_5, t_6, \mathbf{t_2}, t_7 & \rightarrow & r_2: & t_5, t_6, t_7 \\
r_3: & t_8, t_3 & & r_3: & t_8, t_3
\end{array}
$$

Figure 4: An example neighborhood operation.

have on a casualties health state. Our problem involves three possible situations a casualty can be in: trapped, waiting to be rescued; free, waiting to be taken to a hospital; and riding in an ambulance. In order to capture these details in our model, a series of discrete time Markov chains was used to estimate how the health of a casualty will change as time passes. We define three Markov chains - each corresponding to a different situation a casualty can be in over the course of the rescue operation. The dynamics of each chain is shown in Figure 5.

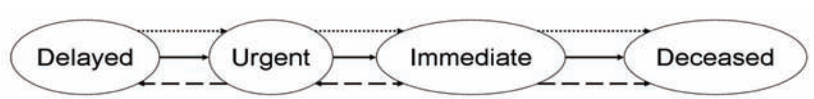

Figure 5: Three Markov chains showing injury level changes, where solid lines correspond to the trapped environment, dotted to awaiting transportation, and dashed to being in an ambulance.

Two health states are linked if it is possible to move from one to the other in any given time step. We see, for example, that casualties riding in an ambulance in a injury state of 'delayed' may move to state 'minor' as they receive basic treatment from paramedics. For the purpose of this case study the actual probability of this transition, and all others, has been estimated.

6 Results and evaluation

To complete the definition of the problem to be considered, we require details of the number of disaster scenes, casualties and resources. We choose these details to mimic the actual emergency of the July 7th bombings. The five disaster scenes and seven hospitals we consider in this problem instance are shown on the map in Figure 2. The number of casualties present at each scene is shown below, together with the expected proportion of casualties in each initial health state (delayed / urgent / immediate / deceased).

As stated in Section 4.1, the capacity of each hospital was set to be twenty percent of the total number of casualties, i.e. 83. The resources available will be spread evenly across the appropriate hospitals and fire stations shown in Figure 2 and will consist of 80 Ambulances, 20 of which are HART trained, and 30 Fire engines. An average speed of 40 miles per hour was used when calculating travel

Table 1: Disaster scene parameters.

Scene	Casualties	Health Distribution	Severity	% Trapped
Edgware Road	58	0.55/0.18/0.14/0.12	0.12	25
Tavistock Square	29	0.15/0.18/0.21/0.47	0.75	1
Kings Cross	143	0.5/0.20/0.16/0.14	0.20	20
Russell Square	54	0.5/0.20/0.16/0.14	0.20	20
Aldgate	128	0.56/0.18/0.14/0.12	0.1	30

times. These figures are designed to approximate those witnessed during the actual London bombings.

Before applying the search algorithm, an initial solution was required. This was created in stages. Firstly, each casualty was assigned to the hospital closest to their initial location, providing that hospital had the required capacity. Secondly, ambulances were assigned a number of casualties they were to take to hospital, and in what order they should be carried out. This was done in such a way as to ensure an even distribution of tasks among ambulances. Furthermore, all casualties with an initial health state of ‘deceased’ were put to the end of their schedule. The allocation of rescue tasks to fire-fighters was carried out in a similar manner. Finally, all optional tasks were omitted from the schedules of this initial solution.

The objective value of the initial solution was calculated to be 116.1. On application of the search algorithm, a solution of objective value 77.1 was obtained, a decrease in the expected number of fatalities of 39. These results suggest there is significant potential for the implementation of the decision support framework to result in an improvement in response operations. Furthermore, qualitative assessment of the framework has been carried out through a number of discussions with emergency planning practitioners from Cleveland Emergency Planning Unit (EPU), Tyne & Wear EPU, Co. Durham & Darlington Civil Contingencies Unit and Government Office for the North East. The feedback received through these discussions has been considered throughout the development of the decision support framework in order to ensure its validity and relevance.

7 Conclusion and further work

By modeling the case study of the London July 7th bombings mathematically, we have been able to capture several pertinent details of the problem. In particular, we have addressed issues arising from the scheduling of a large number of interdependent tasks to a variety of resource types, each with unique capabilities. In addition, we have provided a means to estimate how the health of individual casualties will progress over the course of a response operation, which in turns allows evaluation of a proposed response operation to be undertaken. Given this mathematical model, we have illustrated the potential of solution algorithms in locating high quality solutions.

Further work will involve the development of the model through the addition of more factors relevant to this case study, before further broadening the scope to include other types of no-notice large scale disasters. In addition, we will develop and implement sophisticated algorithms to ensure high quality solutions can be found in an efficient manner.

Acknowledgements

The authors gratefully acknowledge the funding provided under the UK's EPSRC grant EP/G057516/1. Further, the authors thank practitioners from Cleveland EPU, Tyne & Wear EPU, Co. Durham & Darlington CCU and Government Office for the North East. We would also like to thank Co. Durham & Darlington Fire and Rescue Service, North East Ambulance Service, Northumbria Police, and Tyne & Wear Fire and Rescue Service.

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Assessing community and region emergency-services capabilities

Z. Shoemaker, L. Eaton, F. Petit, R. Fisher & M. Collins
Infrastructure Assurance Center, Argonne National Laboratory, USA

Abstract

To increase emergency preparedness for communities, steps must be taken to improve both soft (community planning, education and relationships) and hard (core operational capabilities) aspects of preparedness, resilience and recovery. While professional standards and accreditation organizations continue to improve individual capabilities of first responders and preventers, a tool to analyze a community's full complement of prevention, mitigation, response, and recovery capabilities is still lacking. In order to address this area of concern, Argonne National Laboratory has created a methodology to measure a given community or region's capabilities concerning its entire emergency-services sector. The resulting index accounts for emergency medical, law-enforcement, fire-service, search and rescue, explosive-threat response, 911 dispatch, and emergency-management capabilities, in a way that allows communities to analyze their capabilities relative to other communities of comparable size and hazard profile. The methodology captures a community's aid and assistance agreements to measure expansive and redundant capabilities, as well as the presence of governmental coordination of the services, in a systematic manner. This tool can be used to aid communities in assessing their current capabilities as well as laying out a systematic approach to improving community resilience by targeting specific areas of weakness or areas where leveraging outside capabilities may be difficult.
Keywords: emergency services, capabilities index, regional resilience, critical infrastructures.

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110101

1 Introduction

The resilience of a region is a complex concept combining hard (resilience of institutions and infrastructures) and soft (resilience of citizens) aspects [1]. Multiple definitions and methodologies to assess these aspects of regional resilience exist [2–4]. However, all of these definitions and methodologies emphasize the need to characterize the capabilities of a region to anticipate, absorb, adapt to and recover from a potentially disruptive event [5]. The resilience of a given community or region is then seen as the capability of the region to manage (protect against, mitigate, respond to and recover from) an emergency or a disaster.

Of the 18 critical infrastructure and key resources (CIKR) sectors defined in the U.S. *National Infrastructure Protection Plan* [6], one sector is particularly important to ensuring and ultimately enhancing the Nation's resilience: the emergency-services sector (ESS). As with other CIKR, the resilience of ESS assets directly affects the resilience of a specific region. However, the capabilities of the ESS are also an integral part of the resilience of infrastructures and citizens. The ESS combines the capabilities of all first responders – a key factor in the ability of a region to adapt and react to, as well as recover from, a crisis. As the topic of resilience, its meaning and its importance, is debated, it is vital to identify core functions for resilience management [7]; a high-functioning ESS captures many of those necessary functions.

This paper describes a comprehensive methodology developed to assess ESS capabilities (ESSC), based on their functions, which can be further utilized in characterizing regional resilience. By including the unique response and recovery role of the ESS, researchers can account for the positive impact of a robust ESS on the ability of a region or system to more quickly prevent, respond to and recover from natural or human-caused hazards or, conversely, the negative impact that a low-functioning ESS would have on a jurisdiction. To do so, this paper proposes the use of proxy variables that are closely correlated to an emergency-service subsector\segment's ability to perform certain functions.

2 Emergency-services capabilities

The main objective in analyzing emergency-services capabilities is to capture the impact of the ESS on the organizations and residents of a given jurisdiction. This tends to be a complex task, as directly measuring variables such as operational functions of first responders and preventers can be difficult and time-consuming. For example, physically assessing the ability of a local fire-protection district to identify and extinguish hot spots at an incident scene might require direct observations of the fire-service professionals over an extended period to witness their performance in identifying and extinguishing blazes. For a short assessment process, repeating such an exercise for multiple variables or functions is not feasible.

Using the above example, a more facile method would be to identify whether the professionals have trained and exercised in identifying and extinguishing hot spots, whether they have the equipment necessary to perform the function, and/or whether they have written standard operating procedures for such a task. Although these proxy variables may not always completely define the ability of the fire-service professionals to identify and extinguish hot spots at an incident site, the close correlation of these variables to that ability should still give an accurate depiction of their capabilities. Additionally, measuring a framework that includes planning, training, exercises, procedures, etc., allows researchers to obtain a consistent view of how the organization will function, regardless of the individuals on duty at the time of an incident. Thus, using these proxy variables will allow assessors to conduct the visit more quickly and still reach a valid conclusion.

The ESSC Index (ESSCI) groups nine main "level-1" functions: Emergency Medical Services, Law Enforcement, Fire Services, Search and Rescue, Explosive-Threat Response, Hazardous-Materials Response, Public Safety Answering Point, Emergency Management, and Coordinating Council/Committee. Each of the variables representing the core functions of the ESS captures how specific ESS subsectors/segments operate independently of the others to perform prevention, response and recovery roles, as well as the ability to operate, plan, and exercise together. Each of the nine core functions are characterized by operational capabilities and mutual aid and assistance capabilities. The former analyzes the capabilities of a function to operate on a daily basis in its jurisdiction. This measurement is concerned with potential prevention, response and recovery activities that the function would be able to provide if required. The latter variable (mutual aid and assistance capabilities) analyzes the ability of the function, through documented preexisting agreements, to either supplement its capabilities if they are overwhelmed or lost or to expand its capabilities by having agreements in place for specialized staff or equipment. Combining these two variables gives an overall picture of the resources available to a jurisdiction should a potential incident occur.

Each of the nine functions, except the Coordinating Council/Committee variable, is made up of two level-2 elements: Operational Capabilities and Mutual Aid/Assistance Capabilities. The Coordinating Council/Committee variable does not analyze assistance capabilities, but simply the function of the council or committee. Operational Capabilities group, for each function, five main level-3 capabilities (Facilities/Equipment, Staffing, Training/Exercises, Planning, and Communication) as well as other specific capabilities (e.g., Identification of Hazards, Mitigation Programs, Incident Management, and Resource Management for Emergency Management). These capabilities, defined by sector representatives and subject-matter experts based on various standards in the field [8–10], combine various level-4 characteristics of the ESS.

The ESSCs are thus structured into four levels of information (Functions, Elements, Capabilities and Characteristics) under a tree organization which is based on the multiattribute utility theory (MAUT) [11]. This tree organization of all information characterizing the capabilities of the ESS enables one to obtain an overall index that will allow comparison of the capabilities of different jurisdictions. Indeed, all collected information can be aggregated to calculate an index that represents the capabilities of the ESS to respond to a specific event. The next section explains the methodology used to do so, using as an illustrative example the roll-up of an assessment from the Identification of Hazards characteristic of Emergency Management to the overall index value (ESSCI).

3 Index methodology

Argonne National Laboratory developed a methodology in three steps for the determination of an index that allows for the calculation and comparison of jurisdiction and community prevention, response, and recovery capabilities:

- Collection of data;
- Calculation of ESSCs based on the data collected; and
- Visualization of the capabilities of a jurisdiction and comparison to other like jurisdictions.

3.1 Data collection

The data collection is achieved through a questionnaire that captures the main information (around 375 questions combining over 1800 variables) characterizing emergency-services capabilities in a given jurisdiction. The questionnaire has been developed in collaboration with subject-matter experts to ensure it captures accurate and transparent information that can be compared and interpreted in a consistent manner. The questionnaire was built to be completed by individuals in charge of the various emergency-service functions within a community, and to be done in a limited amount of time. The survey covers the nine core functions of the ESS to prevent, respond to, and recover from a possible incident.

3.2 Calculation of the emergency-services sector capability index

Each question (raw data), and all components and subcomponents of the ESSCI, is assigned a weight representing its importance relative to other questions/components/subcomponents in its grouping. The weights were obtained in accordance with the principles of "decision analysis," an approach that helps manage risk under conditions of uncertainty [12, 13]. The methodology is based on creating a numerical representation of the value pattern by comparing different elements of a jurisdiction and by using relations "better than" and "equal in value to" to define their relative importance. Another important element in this decision analysis tool is the transitivity of the ranking, which means that if an element A is more important than an element B, and B is more important than an element C, then logically A will be more important than C. This approach produces a relational representation of capability alternatives by providing a numerical value assignment for each of its components.

The weights for a set of components depend on the ranges (worst to best) that are included as options in the question set. Preferences for the specific values within the ranges of single components have been provided by subject-matter experts via an elicitation process.

The individual variables are arranged such that they can be aggregated up from the raw-data (level-5) stage into broader variables, culminating through the additive process into an overall ESSCI value. This value is obtained by using a sum of all the weighted components that characterize the capabilities of the ESS.

Table 1 portrays an example for the determination of the Hazard Consequence Analysis Index. For level 4, the weights are divided by the sum of all the weights to determine the individual weight of each component. The optimal plan is one that integrates all of the components and should correspond to an index value of 100.

The emergency-management program in the example has a hazard identification plan that considers the consequences of identified hazards on people, first responders, continuity of operations, and infrastructure. The only element not considered is the consequences on the economy. At the raw-data level, a program is awarded an answer value of 100 for an affirmative answer and a 0 for a negative one. Combining the weighted values of the elements through a summation equation gives a hazard consequence analysis index value of 82.10 (Table 1).

Table 1: Level-4 Hazard consequence analysis index (illustrative example).

Hazard Consequence Analysis Component	Weight	Answer	Weighted Index
The plan documents consideration of people.	0.218	Yes[a]	21.80
The plan documents consideration of first responders.	0.218	Yes	21.80
The plan documents consideration of continuity of operations.	0.190	Yes	19.00
The plan documents consideration of infrastructures.	0.195	Yes	19.50
The plan documents consideration of economy.	0.179	No[b]	0.0
Level-4 Hazard Consequence Analysis Index			82.10

[a] Yes corresponds to a numerical value of 100. [b] No corresponds to a numerical value of 0.

Level-4 characteristics are aggregated into level-3 capabilities, which represent the core capabilities of each ESS function, such as the equipment or staffing or an operational variable such as the identification of hazards for an emergency management program. For example, the hazard consequence analysis variable, level 4, is one of three components of the level-3 Identification of Hazards capability (Table 2).

The hazard identification plan is considered the most important component for the identification of hazards, with a weight of 0.360. The relative importance (weight) of the Hazard Consequence Analysis is 0.310. By multiplying the value

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of the Hazard Consequence Analysis Index (82.10) by its weight, we obtain a weighted Hazard Consequence Analysis value of 25.45. This value is added to the other weighted components that constitute identification of hazards (level 4) to obtain an Identification of Hazards Capability Index of 55.36 (Table 2).

Table 2: Level-3 identification of hazards capability index (illustrative example).

Identification of Hazards Component (Level 4)	Level-4 Weight	Level-4 Index	Weighted Index
Hazard Identification Plan	0.360	50.00	18.00
Hazard Risk Assessment	0.330	36.10	11.91
Hazard Consequence Analysis	0.310	82.10	25.45
Level-3 Identification of Hazards Capability Index			55.36

Level-3 capabilities are aggregated to define level-2 elements. This level represents the two main elements that characterize function (Operational Capabilities and Mutual Aid/Assistance Capabilities). Identification of Hazards is one of the eleven level-3 variables that are aggregated to characterize the operational-capabilities element of emergency management (Table 3).

For Emergency Management, operational capability weights vary from 0.0794 to 0.1148. In the example, the community has a full-time, dedicated Emergency Operations Center with a backup that can handle full-scale operations. However, there is no Joint Information Center (index = 70.18). There is a full-time employee exclusively in charge of emergency management, but supporting members lack specialized training (index = 76.47). All members with emergency-management functions are trained on the emergency-operations plan, but training on other key plans and procedures is missing. Local and regional exercises have been previously conducted with program stakeholders (index = 25.13). The emergency-management program has a comprehensive set of plans; however, these plans do not address financial procedures for recovery (index = 91.68). Mitigation programs include all hazards reasonably mitigated from the hazard identification plan, including goals for risk reduction (index = 86.56). The incident management system lacks several elements, but includes unified command with multiagency coordination (index = 32.88). The community has a resource-management plan but has not conducted a gap analysis (index = 34.55). The community can use different telecommunication methodologies and warning systems (index = 86.56); however, there is no documented plan for public information dissemination or collection (index = 0.00).

The relative importance (weight) of the Identification of Hazards capability is 0.1059. By multiplying the value of the Identification of Hazards Index (55.36) by its weight, we obtain a weighted Identification of Hazards Index of 5.36. This new value is added to the other weighted index values that constitute Emergency Management (level 3) to obtain a level-2 Emergency-Management Operational Capabilities Index of 58.02 (Table 3).

Table 3: Level-2 emergency-management operational capabilities index (illustrative example).

Operational Capabilities Component (Level 3)	Level-3 Weight	Level-3 Index	Weighted Index
Facilities Equipment	0.1118	70.18	7.85
Staffing	0.1148	76.47	8.78
Training/Exercises	0.1088	25.13	2.73
Planning	0.1088	91.68	9.97
Identification of Hazards	0.1059	55.36	5.86
Mitigation Programs	0.0882	86.56	7.63
Incident Management	0.0912	32.88	3.00
Resource Management	0.0882	34.55	3.05
Organizational Communication	0.1029	88.93	9.15
Crisis Communication/Public Information	0.0794	0.00	0.00
Level-2 Emergency-Management Operational Capabilities Index			58.02

Table 4: Level-1 emergency-management index (illustrative example).

Coordination Component (Level 2)	Level-2 Weight	Level-2 Index	Weighted Index
Operational Capabilities	0.752	58.02	43.63
Mutual Aid/Assistance Capabilities	0.248	68.52	16.99
Level-1 Emergency-Management Index			60.62

Level-2 elements are aggregated to define level-1 functions, which represent the major sections of an ESS (Table 4).

Operational Capabilities is considered the most important element for emergency management, with a weight of 0.752. The Mutual Aid/Assistance Agreements element is considered approximately a third as important as the Operational Capabilities element. This would mean that a jurisdiction with the optimal combination of operational capabilities but without any preexisting mutual aid/assistance agreements could achieve a maximum emergency-management index value of 75.20. Conversely, a community with no operational capabilities but a full range of mutual aid/assistance agreements that were taken into account during jurisdictional planning and regularly exercised could achieve a maximum emergency-management index value of 24.80.

The relative importance (weight) of operational capabilities is 0.752. By multiplying the value of the emergency-management operational capabilities index (58.02) by its weight, we obtain a weighted index of 43.63. This value is added to the weighted mutual aid/assistance element (level 2) to obtain an overall emergency-management index of 60.62 (Table 4).

Finally, the overall ESSCI (Table 5) is obtained by aggregating nine level-1 functions: Emergency Medical Services, Law Enforcement, Fire Services, Search and Rescue, Explosive-Threat Response, Hazardous-Materials Response, Public Safety Answering Point, Emergency Management, and the Sector Coordinating Council/Committee. Emergency Medical Services, Law Enforcement and Fire Services were selected as the most important of the nine functions, each receiving a weight of 0.1493. The next most important function is the Public Safety Answering Point, which has a weight of 0.1342, followed by Emergency Management at 0.1269. The remaining five functions have weights that range from 0.0969 for Hazardous Materials Response to 0.0448 for the Coordinating Council/Committee variable.

Table 5: Emergency-services sector capability index (illustrative example).

ESS Function (Level 1)	Level-1 Weight	Level-1 Index	Weighted Index
Emergency Medical Services	0.1493	51.08	7.63
Law Enforcement	0.1493	67.45	10.07
Fire Services	0.1493	69.21	10.33
Search and Rescue	0.0672	47.43	3.19
Explosive Threat Response	0.0821	0.00	0.00
Hazardous Materials Response	0.0969	16.89	1.64
Public Safety Answering Point	0.1342	74.75	10.03
Emergency Management	0.1269	60.62	7.69
Coordinating Council/Committee	0.0448	26.52	1.19
Overall Emergency-Services Sector Capability Index			51.77

The jurisdiction characterized in this example has fairly robust Law-Enforcement, Fire-Services, Public Safety Answering Point, and Emergency-Management functions. The jurisdiction only has the services of a hazardous-materials response team through mutual aid/assistance agreements and does not have an explosive-threat response team in the jurisdiction, nor does it have preexisting agreements to identify who would provide those services if needed.

By multiplying the value of the emergency-management index by its weight (0.1269), we obtain a weighted emergency-management index of 7.69. This value is added to the other weighted index values of emergency-services functions to obtain an overall ESSCI of 51.77 (Table 5).

This method of characterizing the capabilities of the ESS of a jurisdiction allows for consideration of the impact of emergency services on the individuals within the supported community and CIKR resilience within its region, as well as how capabilities vary within the sector as a whole. A score of 100 on the ESSCI is not necessarily the expected level of capability for emergency-services programs. Rather, a score of 100 would represent an optimal program that would rarely be observed. An expected level of capability would come not from a pre-fixed number on the index, but rather, from an analysis of the average capability score, combined with examination of minimally acceptable capabilities from within each of the Level-1 and -2 variables.

The information required to complete the ESSCI is collected during an on-site assessment visit; however, a self-assessed ESSCI score could also be derived if deemed appropriate. In this case, the data would be obtained from a survey that corresponds to the variables in the index and that could be modified to reflect future changes. This index, based on a jurisdiction's capabilities in terms of emergency services, is also useful to integrate into separate programs that characterize vulnerability and resilience of a region or system.

3.3 Visualization of the capabilities of a jurisdiction

Although an individual ESSCI value is important with regard to the data it represents, it can be difficult to fully interpret without context. Without a frame of reference, the ESSCI's value does not convey its full meaning. For instance, when there is no understanding of the other scores, does an overall ESSCI score of 51.77 lead one to believe that a jurisdiction is well prepared to prevent or respond to an emergency? Indeed, the value of an ESSCI is strongly related to the jurisdiction and its environment. A comparative framework is thus necessary. Using an ESSCI value to compare similar jurisdictions with respect to regional resilience can provide additional vital benefits.

To facilitate comparisons between different possible actions, Argonne has developed a Web-based tool, the ESS Dashboard. This tool allows city or county officials, simply by selecting possible options to consider and changing characteristics at each level, to immediately see the benefits of potential changes to the overall values of the calculated indices.

The Dashboard provides various interactive windows that are particularly relevant to supporting decisions for proactive disaster prevention and management. Figure 1 shows an example of these windows for the communication capability of the Fire-Services function. It shows the different possible options for consideration for communication; three counters give the values for the overall index as well as for the selected function (Fire Services) and element (Operational Capabilities). The Dashboard gives users the ability to change parameters, speedily see results, and assess different scenarios, making it a very powerful tool that is particularly relevant with regard to strategic planning and budgeting.

Combining multiple jurisdiction ESSCI values into a region-specific dashboard adds a new level of information. Region-specific ESSCIs demonstrate the potential effects of prioritizing measures for a particular jurisdiction beyond its own immediate benefits. The list of common options, identified through comparisons with those of other jurisdictions, can help city or county officials make decisions regarding a region-specific resilience and prepardness strategy.

The ESSCI can be used to aid communities in assessing their current capabilities as well as laying out a systematic approach to improving capabilities by targeting specific areas of weakness or areas where leveraging outside capabilities may be difficult. It can be combined with other elements to characterize the resilience of a region.

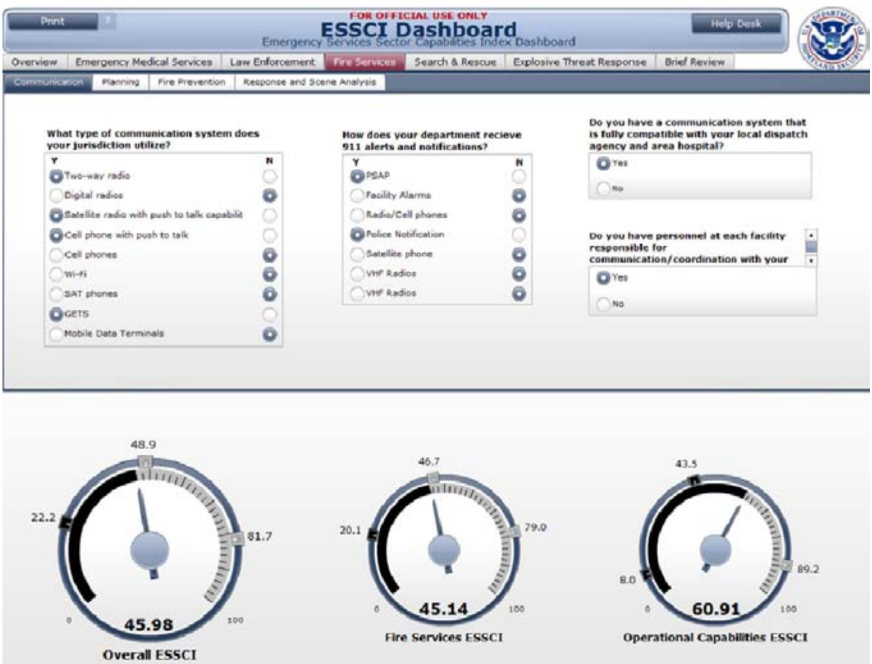

Figure 1: The ESSCI dashboard screen.

4 Applicability of the ESSCI to assessing regional resilience

Community resilience or regional resilience can be defined as the capability of a geographic location, its inhabitants and organizations to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change [14]. Regional resilience is thus related to the capabilities of a jurisdiction to resist, adapt to, and recover from a disruptive event. To fully measure regional resilience, all component parts (e.g. people, institutions and organizations) must be taken into account. In order to do so, the topic is often separated into two main aspects to be analyzed: soft and hard [1]. Soft aspects include the capacities of individuals and institutions to adopt and maintain a planning mindset, develop physical and psychological toughness, be self-sufficient, respond appropriately in the face of a disaster, and learn and adapt [1]. Hard aspects include the capacities of governments, organizations and systems to maintain structures and services (i.e., CIKR), recover quickly, shift from degraded to alternative resources, and learn and adapt [1]. The ESS serves a critical role in soft aspects of regional resilience as it constitutes the community's first line of defense and helps frame a community mindset, while it also plays an integral role in hard aspects through hazard prevention and reduction of consequences from natural and human-caused hazards [15]. Thus, while the characterization of the ESS is only one of the elements that need to be considered in order to analyze the overall resilience of a geographic area, capturing the capabilities of the ESS is vital as it promotes both hard and soft aspects of regional resilience. The ESS is a critical infrastructure sector that needs to be itself resilient to both natural and man-made hazards as well as serve as a tool to promote resilience of other infrastructures and facilities.

Beyond its own benefits, the ESSCI also complements other indices that have been developed by Argonne National Laboratory to assess the protection, vulnerability, resilience, and criticality of facilities combined with information about the susceptibility of assets to specific threat types [2, 16]. By combining these indices with other programs utilized by DHS along with other tools to more specifically assess the soft aspects of regional resilience, it is possible to form a more thorough representation of specific area resilience and of risk in general.

5 Conclusion

In a complex and interconnected world, it is vital to enhance the preparedness and resilience of society. The ESS is uniquely important as it constitutes a core function in the resilience of all CIKR sectors as well as the population in general; therefore, it is essential to consider its vulnerability, resilience, criticality, and capabilities if we are to accurately assess the risk and resilience of a geographic area. The proposed ESSCI, based on accepted programmatic elements, allows for consideration of the particular capabilities of the ESS in a global methodology.

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Community resilience: measuring a community's ability to withstand

M. Collins, J. Carlson & F. Petit
Argonne National Laboratory, USA

Abstract

Several recent studies have provided a range of perspectives on the role of *resilience* in policies and programs designed to address natural and man-made threats. A review of those studies reveals that there is strong agreement that the concept of resilience must play a major role in assessing the extent to which various entities—critical infrastructure and key resources, systems, communities, and regions—are prepared to deal with the full range of threats they face. As resilience assessment methodologies continue to be developed and implemented for resilience at various levels, it is critical that a framework be developed to utilize measurements of resilience at multiple levels to characterize a community's resilience to potential hazards. Argonne National Laboratory, in partnership with the U.S. Department of Homeland Security, has developed a framework that combines existing measures of critical infrastructure and organization resilience with new measurement tools in order to characterize five subsystems of a community: the economy, physical infrastructure, government and nongovernmental organizations, emergency services, and the civilian population. The resilience of each of these subsystems will be measured through various tools, including an assessment of economic diversity; a review of community continuity of operations and government plans for essential functions; an analysis of critical infrastructure and organizational resilience to include lifeline utilities and vital private sector organizations; a study of disaster public education; communication and evacuation programs; and a review of the emergency services capabilities that a community possesses. Through the application of these measures, a community can better understand its current resilience posture, as well as implement a systematic approach to reduce vulnerabilities and consequences of potential hazards.
Keywords: resilience, community resilience, disaster preparedness, critical infrastructure resilience, risk mitigation, emergency management.

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110111

1 Introduction

Several recent studies (see [1–8, 12], for example) have provided a range of perspectives on the role of *resilience* in policies and programs designed to address natural and man-made threats. A review of those studies reveals that there is strong agreement that the concept of resilience must play a major role in assessing the extent to which various entities—critical infrastructure and key resources, systems (e.g., electricity generation, transmission and distribution), communities, and regions—are prepared to deal with the full range of threats they face.

Agreement regarding the importance of resilience notwithstanding, there is considerable disagreement over a number of issues associated with the concept. These include how resilience should be defined, whether it is an outcome or a process, and the type of resilience a particular analysis is considering [4, 5].

This paper has two primary objectives. The first is to develop a clear distinction between resilience as it relates to critical infrastructure and *community resilience*. The second is to develop a framework for constructing a measure of community resilience that can be combined with existing measures of asset readiness to provide a quantitative assessment of risk mitigation across different assets and levels of aggregation (e.g., systems, communities, regions).

2 Resilience defined

As noted in the introduction, there is no single, universally agreed-upon definition of resilience. Instead, its definition and measurement vary with respect to type (e.g., economic, engineering, ecological) and focus (e.g., community [societal], critical infrastructure, supply chain). When focusing on resilience as it relates to managing risks attributable to natural or man-made threats, one of the most significant disagreements concerns the question of whether resistance (i.e., protection) should be included as a component of resilience. As part of their analysis of community resilience, Norris *et al* [3] completed a review of the literature on resilience. On the basis of their review, they concluded that

> "[r]esilience has been defined in a variety of ways.… Most definitions emphasize a capacity for successful adaptation in the face of disturbance, stress, or adversity. Although there are exceptions, most discussions, if not the definitions themselves, distinguish resilience from 'resistance'" (p. 129).

The authors provided a summary of the definitions of resilience found in 21 of the articles they reviewed. Of those 21 definitions, 16 define resilience as capacities/actions that occur *after* some type of disturbance, stress, or adverse event has occurred. Consistent with the findings of Norris *et al* [3], several of the studies we reviewed [1, 3, 5, 7, 13 (citing [2])] describe resilience as the ability of an entity to recover, or "bounce back," from the adverse effects of a natural or man-made threat. These definitions take the position, either explicitly or implicitly, that protection and resilience are distinct elements of an overall strategy to address such threats.

In contrast, the U.S. Department of Homeland Security (DHS) [9], the Homeland Security Studies and Analysis Institute (HSI) [5], and the National Science and Technology Council's Subcommittee on Disaster Reduction (SDR) [10] explicitly include resistance in their definitions of resilience.

2.1 Reconciling different definitions

Regarding the question of whether resistance should be included in the assessment of resilience, Cutter *et al* [4] argue that:

> More recent research on resilience from a homeland security perspective (primarily protecting critical infrastructure from terrorism) [5] also focuses on critical infrastructure resilience assuming that resilience is an outcome measure with an end goal of limiting damage to infrastructure (termed resistance); mitigating the consequences (called absorption); and recovery to the pre-event state (termed restoration). While perhaps useful for counterterrorism and protection of critical infrastructure, this operational framework ignores the dynamic social nature of communities and the process of enhancing and fostering resilience within and between communities (p. 2).

There are two important points here. First, defining resilience to include resistance reflects a view that resilience is an outcome, as opposed to a process. Second, the appropriate definition of resilience is context dependent. In this case, one could argue that the definition offered by DHS and Kahan *et al* [5] is appropriate when attention is focused on CIKR. In contrast, when the focus is on *community resilience,* a definition that focuses on adaptation and recovery, and explicitly ignores resistance, is preferred.

2.1.1 Critical infrastructure resilience versus community resilience

The justification for the distinction between resilience at the asset level versus the community level rests on the following points. First, limiting our focus to terrorist threats, experience to date suggests that an attack will focus on a specific asset or collection of assets—buildings, buses, trains, airplanes. In this scenario, *protection* is more appropriately addressed by the individual assets (i.e., critical infrastructure) that are the likely target of an attack. (Even if we think in terms of a system, ultimately protection must be addressed by the individual elements of the system, e.g., generation, distribution, transmission, and independent system operators in the electricity sector.) The notion that communities should engage in protective measures would invariably require that they focus on individual assets and systems; however, the owners/managers of individual assets are much better positioned to identify the protective measures currently in place and to evaluate the incremental value of additional protective measures. As such, communities would make better use of limited resources by leaving this aspect of risk management to the individual assets.

Second, focusing on the time dimension of a threat, protection/resistance consists of actions that are taken prior to a threat's occurrence either to forestall it or to reduce (mitigate) its adverse effects. Once the threat has been "realized" in the form of a successful attack, attention shifts to the ability of the affected entity—asset, system, community, region—to maintain functions, absorb impacts, adapt response(s), degrade in a graceful manner as opposed to abruptly, recover functions, and restore operations. Here again, it makes sense to include some consideration of protection in the critical infrastructure-level measure of resilience. This approach is taken because the level of protection the asset has put into place prior to an event will undoubtedly influence the level of damage ultimately sustained and, consequently, the asset's ability to recover and maintain its core functions. This ability at the asset level will, in turn, feed into the extent of the community's overall ability to absorb, adapt to, and recover from the adverse effects of the attack.

Risk management at the community level requires consideration of both the risks faced by CIKR and the community's ability to respond, adapt to, and recover from a disruptive event. The latter can be captured by measuring the community's resilience. The next two sections of this paper address two related issues: (1) the definition of community resilience, and (2) how to measure community resilience.

3 Community resilience

Argonne National Laboratory (Argonne) [11] has developed a methodology that can be used to measure the resilience of critical infrastructure. This measure is appropriate when assessing risk and risk mitigation efforts directed at specific critical infrastructure assets. If, however, the focus is on communities, a different measure of resilience is needed. Our review of the literature yielded four recent studies—Norris *et al* [3] , Stewart *et al* [8], Longstaff *et al* [6], and Cutter *et al* [4]—that specifically address the determinants of community resilience. Of these, the latter three studies address the measurement of community resilience as well.

The study by Norris *et al* [3] presents a comprehensive review of the literature on resilience and develops a model of how community resilience is determined. According to Norris *et al* [3], "[c]ommunity resilience is a process linking a network of adaptive capacities (resources with dynamic attributes) to adaptation after a disturbance or adversity" (p. 127). In addition, "resilience rests on both the resources themselves and the dynamic attributes of those resources …we use the term 'adaptive capacities' to capture this combination" (p. 135). The dynamic attributes (properties) of resilience resources include robustness, redundancy, and rapidity. Norris *et al* [3] also identify four sets of "networked resources" that are responsible for determining community resilience: economic development, social capital, information and communication, and community competence.

The authors use their model of community resilience to identify a set of actions they believe will enhance community resilience to disasters. The set of actions includes: (1) developing economic resources, reducing risk and resource inequalities, and addressing areas of greatest social vulnerability; (2) meaningfully engaging local people in every step of the mitigation process so as to access social capital; (3) developing organizational networks and relationships that will rapidly mobilize emergency and ongoing support services in the event of a disaster; (4) engaging in interventions that boost and protect naturally occurring social supports in the aftermath of disasters; and (5) exercising flexibility and focusing on building effective and trusted information and communication resources that function in the face of unknowns.

While adopting the definition of resilience offered by Norris *et al* [3], Stewart *et al* [8] identify supply chain resilience, critical infrastructure resilience, economic resilience, social resilience, and public-private partnerships (PPPs) as the primary determinants of community resilience. In their model, the resilience of relevant supply chains and the critical infrastructure that exist in the community affect one another and, in conjunction with the community's economic and social resilience, determine the level of community resilience. In addition, the relationships that government (public) agencies develop with private sector partners (i.e., PPPs), can positively influence supply chain and critical infrastructure resilience.

Longstaff *et al* [6] define community resilience as "the ability of a community to absorb a disturbance while retaining its essential functions" (p. 4). In the authors' model, community resilience is a function of resource robustness and adaptive capacity. Resource robustness is measured by resource performance, redundancy, and diversity. Adaptive capacity is measured by institutional memory, innovative learning, and connectedness. Community resilience is determined by the resource robustness and adaptive capacity of each of five key community subsystems: ecological, economic, civil society, governance, and physical infrastructure.

A recent study by Cutter *et al* [4] provides a framework for assessment of community resilience and then applies that framework to the counties in the Federal Emergency Management Agency's Region IV. Although the authors do not offer a formal definition of community resilience, their approach explicitly focuses on the ability to respond to and recover from a threat once it has been realized. On the basis of a theoretical model, the authors include the following five categories in their measure of community resilience: social resilience, economic resilience, institutional resilience, infrastructure resilience, and community capital resilience.

3.1 Comparison/contrast of the four studies

Focusing first on the definition employed in each study, there is relatively little difference (practically speaking) among the four studies. All four tend to focus on how the community responds after a threat has been realized; that is, protection/resistance is not included in any of the definitions. There is considerably more variation, however, among the studies regarding the primary determinants of community resilience. Taken together, the four studies identify 14 different components that are assumed to affect community resilience. As the

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following summary of definitions and possible measures shows, however, there is overlap among the individual components.

Economic resilience: Economic resilience is the only component included in all four of the models considered herein. There is also a fair amount of agreement regarding the variables that Stewart *et al* [8], Longstaff *et al* [6], and Cutter *et al* [4] suggest ought to be included in the measurement of economic resilience (e.g., employment statistics, income equality, labor market conditions, and business diversification).

Civil society/Community capital resilience/Community competence/Social capital/Social resilience: In comparing the definitions of civil society in Longstaff *et al* [6], community capital resilience in Cutter *et al* [4], community competence and social capital in Norris *et al* [3], and social resilience in Stewart *et al* [8], some degree of overlap is suggested. This impression is reinforced when we consider the specific measures of resilience for these components as suggested in each study.

Ecological resilience: The study by Longstaff *et al* [6] is the only one that includes ecological resilience in its measure of community resilience. Their suggested measures of ecological resilience include water supplies, wind patterns, climate, soil quality, topography, diversity of habitats, agricultural diversity, how quickly key elements of the local environment can regenerate in the event of a disaster, and the ability of the environment to support a diversity of crops and wildlife.

Governance resilience/Institutional resilience: The study by Longstaff *et al* [6] includes governance resilience in its measure of community resilience. There is some overlap between governance resilience and institutional resilience, which Cutter *et al* [4] include in their model. For example, Longstaff *et al* [6] refer to the connectedness of the various units of government in times of disruption, while Cutter *et al* [4] focus on political fragmentation. In addition, Longstaff *et al* [6] point to the cost and quality of services delivered in relation to the resources collected from citizens, while Cutter *et al* [4] suggest including the percentage of municipal expenditures that are apportioned for fire, police, and emergency medical services.

Critical infrastructure/Physical infrastructure/Infrastructure: There is a high degree of overlap as it relates to the definitions of critical infrastructure resilience in Stewart *et al* [8] and physical infrastructure in Longstaff *et al* [6]. However, there is considerably less overlap between the definitions proposed by these two and the measurement of infrastructure proposed by Cutter *et al* [4].

Public-private partnerships: The study by Stewart *et al* [8] is the only one to explicitly model PPPs as a determinant of community resilience. PPPs enter the model through their effects on critical infrastructure and supply chain resilience. Longstaff *et al* [6] do, however, refer to PPPs in their definition of governance resilience.

Supply chain resilience: The study by Stewart *et al* [8] is the only one to explicitly include supply chain resilience in its list of the determinants of community resilience. The authors' suggested measures of supply chain resilience include redundancy, flexibility, density, complexity, node criticality, and public-private partnerships.

4 Calculating a community resilience index

In this section, we propose a process for measuring community resilience. To do that, we must first establish a working definition of community resilience and specify a model that explains how community resilience is determined.

4.1 A working definition of community resilience

As discussed in Section 2 of this paper, a review of the general concept of resilience reveals that most of the disagreement among competing definitions concerns whether protection/resistance should be included as an element of resilience. That being said, this issue appears to arise only with respect to the general concept of resilience. Our review of analyses of community resilience revealed no such disagreement; none of the four studies reviewed in this paper includes protection/resistance in their definitions of resilience. The definitions include the following:

- Norris *et al* [3]/Stewart *et al* [8]: Community resilience is a process linking a network of adaptive capacities (resources with dynamic attributes) to adaptation after a disturbance or adversity.
- Longstaff *et al* [6]: Community resilience is the ability of a community to absorb a disturbance while retaining its essential functions.
- Cutter *et al* [4]: Their definition focuses on the ability to respond to and recover from a threat once it has been realized.

The key terms employed in these definitions include absorb, adapt, respond, and recover. While one might be tempted to think of these elements in a sequential fashion (e.g., first absorb, then respond/adapt, and finally recover), we argue that actions associated with each of these elements of resilience are interdependent and can occur simultaneously. Based on the preceding discussion, we define community resilience as "*the ability of a community to absorb, respond/adapt to, and recover from a disturbance while retaining its essential functions*."

4.2 Determinants of community resilience

The next step is to specify a model that identifies the primary determinants of community resilience. Referring again to the studies reviewed in Section 3, community resilience is a function of some set of subsystems or networked resources. For purposes of comparison, we assume that the terms "subsystem" and "set of networked resources" are functionally equivalent. Each of the four models considered herein can be summarized as follows:

- Norris *et al* [3] view community resilience as a function of the resilience of four sets of networked resources—economic development, social capital, information and communication, and community competence—which, in turn, determine community resilience.

- Stewart *et al* [8] view community resilience as a function of supply chain resilience, critical infrastructure resilience, economic resilience, social resilience, and PPPs.
- Longstaff *et al* [6] view community resilience as a function of the resilience of five subsystems—ecological, economic, civil society, governance, and physical infrastructure.
- Cutter *et al* [4] include the following five categories in their measure of community resilience: social resilience, economic resilience, institutional resilience, infrastructure resilience, and community capital resilience.

Taken together, subsystems that might contribute to the assessment of community resilience include: economic resilience, ecological resilience, critical infrastructure/physical infrastructure/infrastructure resilience, governance/institutional resilience, civil society/community capital/community competence/social capital/social resilience, information and communication resilience, and supply chain resilience.

The model we propose to use to measure community resilience is adapted from the list of subsystems listed above. According to our model, *community resilience is a function of the resilience of the following subsystems: the community's economy, critical infrastructure (selected components), governmental and nongovernmental services (institutions), emergency services sector, and the civilian population*. The justification for each of the components included in our model is as follows.

- *Economic resilience*: Economic resilience is included in all four models reviewed herein and clearly has important implications for the ability of a community to "bounce back" from a disturbance, such as a terrorist attack.
- *Infrastructure resilience*: In our model, infrastructure resilience is a function of a subset of critical infrastructure sectors (Commercial Facilities, Communications, Information Technology, Energy, Healthcare and Public Health, Transportation Systems, and Water). These specific sectors were selected on the basis of their relationship to such concepts as adaptation and recovery of a community once a threat has been realized.
- *Institutional resilience*: The ability of governmental or nongovernmental units to continue to function in the event of a disturbance will obviously have a profound impact on the community's ability to absorb, respond to, and recover from the disturbance. This view is reflected in the considerable emphasis that DHS has placed on the development of continuity of operations plans and continuity of government plans at all levels.
- *Emergency services sector resilience*: Emergency services will also have a large impact on the community's ability to absorb, respond to, and recover from a disturbance, and this subsystem encompasses information and communication resilience as called for by Norris *et al* [3].
- *Civilian population resilience*: In Section 3.1, we argue that civil society, community capital resilience, community competence, social capital, and social resilience are roughly similar concepts that focus, to varying degrees,

on the ability of a community's general public to respond to a disturbance. It should be clear that the public's inability to adapt, respond to, and recover from a disturbance will seriously limit the community's ability to bounce back, regardless of the resiliency of the other subsystems included here. Thus, our model includes a measure of the resilience of the community's civilian population.

Depending on whether the measurement of community resilience focuses on man-made or naturally occurring hazards, we may include measures of supply chain and/or ecological resilience as well.

4.3 Determinants of resilience of subsystems

The next step in this process is to identify properties/characteristics that can be used to assess the resilience of each of the subsystems included in our model. The studies by Norris *et al* [3], Longstaff *et al* [6], and Argonne [11] offer guidance in this regard. Norris *et al* [3] use the properties of *robustness, redundancy,* and *rapidity* to assess the resilience of networked resources. Longstaff *et al* [6] use the properties of *resource robustness* and *adaptive capacity* to assess the resilience of subsystems. Argonne [11] uses the properties of *robustness*, *resourcefulness*, and *rapid recovery* to assess critical infrastructure resilience.

The key terms listed above—robustness, redundancy, resourcefulness, rapidity, recovery, and adaptive capacity—are defined as follows:

- *Robustness*: Norris *et al* [3] define robustness as the ability to withstand stress without suffering degradation, while Argonne [11] defines it as the ability to maintain critical operations and functions in the face of crisis. Regarding measures of robustness, Longstaff *et al* [6] cite resource performance, redundancy, and diversity, whereas Argonne [11] focuses on redundancy, prevention/mitigation, and the ability to maintain key functions.
- *Redundancy*: Norris *et al* [3] define redundancy as the extent to which elements are substitutable in the event of disruption or degradation. Comparing the three approaches, however, we believe it is more appropriate to designate redundancy as a determinant of robustness as is suggested by Longstaff *et al* [6], National Infrastructure Advisory Council [7], and Argonne [11].
- *Resourcefulness*: Norris *et al* [3] define resourcefulness as the capacity to identify problems and mobilize resources. Argonne [11] defines resourcefulness as the ability to skillfully prepare for, respond to, and manage a crisis and suggests several possible measures of resourcefulness, including the conduct of training exercises and the existence of stockpiles, protective measures, alternative sites, awareness, new resources, and response capabilities.
- *Rapidity*: Norris *et al* [3] defines rapidity as the speed with which a resource can be accessed and used (includes the property of resourcefulness).
- *Rapid Recovery*: Argonne [11] defines rapid recovery as the ability to return to and/or reconstitute normal operations as quickly and efficiently as possible

after a disruption and suggests coordination and restoration as possible measures.

- *Adaptive Capacity*: According to Longstaff *et al* [6], adaptive capacity “is a function of the ability of individuals and groups to: (1) store and *remember* experiences; (2) use that memory and experience to learn, *innovate*, and reorganize resources in order to adapt to changing environmental demands; and (3) *connect* with others inside and outside the community to communicate experiences and lessons learned, self-organize or reorganize in the absence of direction, or to obtain resources from outside sources” (p. 7). The authors also cite possible measures of adaptive capacity, including institutional memory, innovative learning, and connectedness.

In our model, the resilience of each subsystem is a function of robustness, resourcefulness, rapid recovery, and adaptive capacity.

4.4 Quantifying community resilience

Regarding the quantification of resilience, we envision constructing a set of indices that measure the resilience of each of the subsystems included in our model of community resilience. Indices of this type are referred to as composite indicators. According to Cutter *et al* [4]:

> [a] composite indicator is the mathematical combination of individual variables or thematic sets of variables that represent different dimensions of a concept that cannot be fully captured by any individual indicator alone. Composite indicators are increasingly recognized as useful tools for policy making and public communication because they convey information that may be utilized as performance measures (pp. 2–3).

The specific indices include the following:

- *Economic Resilience Index*: Using the properties/characteristics described in the preceding section, a set of variables will be identified that can be used to produce an Economic Resilience Index (ERI). This index will capture the ability of the vital economic components of a community to survive disruptions and/or quickly stand back up to maintain the economic viability of a given community.
- *Infrastructure Resilience Index*: The Resilience Index (RI) developed by Argonne [11] will be used to measure the resilience of individual sectors, which could be segregated to life-line utilities: Communications, Information Technology, Energy, Healthcare and Public Health, Transportation Systems, and Water. The individual RIs will then be rolled up into a single Infrastructure Resilience Index (IRI) that will portray the overall resilience of the infrastructure located within and servicing the community.
- *Institutional Resilience Index*: In order to capture the resilience of the individual governmental and nongovernmental organizations that provide vital functions to the community, an index measuring the specific framework of the organizations combined with a review of necessary continuity of

operations and continuity of government (COOP/COG) plans will be developed.

- *Emergency Services Sector Capabilities Index*: The Emergency Services Sector Capability Index (ESSCI), developed by Argonne, focuses on the various dimensions of emergency services, including emergency medical services, law enforcement, fire services, search and rescue, explosive threat response, hazardous materials response, emergency management, and response and coordination capabilities, as well as the ability to communicate with and inform the public (thus capturing information and communication resilience as called for by Norris *et al* [3]). This index will be utilized to characterize the ability of a given community to protect its citizens, infrastructure, and organizations from possible hazards; mitigate potential impacts; quickly and efficiently respond once an event occurs; and then organize long-term recovery procedures.
- *Public Preparedness Index*: Utilizing the Public Preparedness Index (PPI) currently in production at Argonne National Laboratory, a review will be conducted of a community's public emergency preparedness programs, warning systems, and crisis communication methods, as well as other methods of preparing and caring for individuals before, during, and after an event.

Once the individual indices—ERI, RI, IRI, COOP/COG Review, ESSCI, and PPI—have been applied to a given community, they will be presented individually rather than being rolled up into a single measure. Creating a single metric would mask a great deal of information and would reduce the ability to analyze different possible combinations of resilience across the five subsystems. In particular, examining each of the indices individually and in relation to one another will provide decision makers with a more detailed picture of a community's current resilience posture. In addition, it will facilitate identification of those areas in which investment of additional resources to bolster resilience is likely to yield the greatest return per dollar spent.

5 Summary

In order to better understand the ability of individual communities to absorb, respond/adapt to, and recover from a disturbance while retaining their essential functions, emergency planners must understand the resilience attributes of the subsystems that make up a community. In order to do so, we have identified five subsystems that characterize the citizens of a community, the services provided to the residents of the community, and the infrastructure—economic and otherwise—that make the community a viable option for current or future residents. Having identified those subsystems, we have also developed separate measures of each (i.e., the indices described in Section 4.4) to help communities characterize their abilities to withstand and recover from a potential incident or attack. Gaining a better understanding of each of the components enables a more thorough analysis of the strengths and weaknesses of a community in terms of resilience, as well as a prioritized list of options to consider when contemplating how best to improve overall community resilience. The effort to improve community resilience does not guarantee that incidents will not occur, nor does such an effort guarantee that if incidents do occur, the community will be able to avoid serious impacts. However, it does allow a community to be proactive in reframing its programs, services, and organizations in a way to better prepare for potential hazards.

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Emergency response and traffic congestion: the dispatcher's perspective

V. P. Sisiopiku[1], A. J. Sullivan[1], P. J. Foster[2] & P. R. Fine[2]
[1]*Department of Civil, Construction, and Environmental Engineering, University of Alabama at Birmingham, USA*
[2]*Department of Medicine, University of Alabama at Birmingham, USA*

Abstract

Traffic congestion may impede the ability of emergency vehicles to reach the site of a traffic incident or other disaster in a fast and reliable manner. It is imperative that emergency dispatchers use real time traffic information in order to improve dispatching of Emergency Medical Services (EMS) to the disaster site. Preliminary research indicates, however, that many dispatchers have not been trained to cope with severe congestion nor have they been given the tools that would allow them to consider traffic congestion in the dispatching process. In order to (a) document the extend of this problem in the state of Alabama and (b) understand how traffic congestion impacts emergency dispatching decisions and response, this study developed and conducted a statewide survey of emergency dispatchers on behalf of the University Transportation Center at the University of Alabama at Birmingham. The survey sought feedback from EMS dispatchers in Alabama on current practices, positive and negative experiences, preferences, as well as their perceptions on the use of real time traffic data to help optimize emergency response and transport times. The results of the survey analysis clearly show that there is a disconnect between dispatching decisions and conditions in the field. Traffic congestion was generally not viewed as a major concern among the dispatchers surveyed nor was any real time traffic information used to improve decision making at the dispatching control center. Availability of real-time traffic information for dispatching purposes, and education of dispatchers about the opportunities and benefits that can be realized by using such information are very important steps toward improving Emergency Medical Services (EMS) performance and reliability, which in return can improve survivability of victims requiring medical attention.
Keywords: emergency dispatch, traffic congestion, Alabama.

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110121

1 Introduction

Traffic congestion is a primary concern during incident response and can create difficulties for emergency vehicles attempting to enter and exit affected areas. Utilizing real-time information on traffic conditions in support of dispatching decision-making can reduce emergency responders' arrival time to the scene, resulting in faster delivery of medical services, and improved health outcomes of crash victims. However, many of the dispatchers who would be responsible for directing the movements of emergency response units during emergencies have not been trained to cope with congestion nor have they been given the tools that would allow them to consider traffic congestion in the dispatching process.

A review of available literature found that while many computer aided dispatch (CAD) systems have the capability to incorporate real-time traffic data into their dispatch algorithms, few agencies nationwide actually use this feature. Furthermore, an informal survey of emergency response agencies in the Birmingham, Alabama area found that traffic conditions are typically not considered when dispatching a response unit.

1.1 Objective

In an effort to explore these concerns the University of Alabama at Birmingham (UAB) University Transportation Center sought to answer some fundamental questions concerning traffic congestion and emergency response in Alabama, specifically:

- To what degree do emergency dispatchers believe traffic congestion impacts response times in their jurisdiction and how does this compare with the actual experiences of the emergency responders in the field?
- To what degree, if at all, do emergency dispatchers consider traffic conditions when selecting a unit to dispatch?
- Do emergency dispatchers receive training to cope with traffic congestion? Do they have tools that allow them to consider traffic conditions when dispatching a unit?
- What tools would be most useful to dispatchers to enhance the current dispatch process?

In order to gain a better understanding of current dispatching practices as they relate to congestion the UAB University Transportation Center (UTC) undertook two separate surveys of emergency service providers across the state of Alabama. The first was a survey of emergency responders (i.e., the units in the field) to gauge how often they encounter traffic congestion during calls and the extent to which they feel it increases response times. The second was a survey of emergency dispatchers designed to gauge the extent to which they believe traffic congestion impacts emergency response times and what tools they use to address it. This paper presents the results of the dispatcher survey but also includes some findings from the responder survey to allow comparisons between the two.

1.2 Methodology

Initial interviews with emergency responders and dispatchers in the Birmingham area found significant differences in how these two groups perceive traffic congestion and its impacts. In general, our interviews indicated that dispatchers tended to see congestion as less of a problem than responders did. Responders, in turn, expressed a lack of confidence in the accuracy of information conveyed to them by the dispatchers, both with respect to traffic congestion and the nature and location of the emergency.

To investigate these differences it was decided to administer separate but similar surveys for each group. The responder and dispatcher surveys were developed in parallel and designed to obtain similar information from each group. Initial meetings were held with responders and dispatchers in the Birmingham region to better understand current dispatch and response practices and identify the types of issues each group feels are important to their jobs. Meetings with the groups were scheduled separately (i.e., dispatchers and responders were not present at the same meetings) and this made the research group aware of differences in how each group perceives the impacts of traffic congestion. Survey questions were developed based on these meetings and in part designed to clarify some of these differences.

The dispatcher survey solicited the following types of information:

- Employing agency, type of area served (urban or rural), typical volume of calls handled;
- Dispatcher duties, typical work shifts, types of dispatching and monitoring equipment used;
- Dispatcher experience and training;
- Views of congestion and its impact on response times;
- Systems available to monitor or consider congestion in dispatching;
- Suggestions for improving the dispatch process.

Alabama has numerous medium and small-sized urban areas as well as large portions that are rural. It was decided to survey dispatchers in both urban and rural areas in order to gain an understanding of how congestion impacts emergency response under different levels of population. It was also decided that while the survey would focus on Emergency Medical Service (EMS) dispatchers, we would also survey police and fire dispatchers since these duties are shared in many smaller cities and rural areas.

The survey tool used in this study was electronic and is available online at: https://spreadsheets.google.com/viewform?formkey=dHI5RFE5NVlBbkladTJrZjJyYUEyV3c6MA The initial surveys were broadcast via listservs used by emergency dispatchers in the state.

The response rate for this initial solicitation, however, was poor. To increase the response rate, selected public safety access points (PSAPs) in the state were contacted to solicit their participation in the survey. The PSAP’s are the primary 9-1-1 call centers serving police, fire, and rescue services in a given area. In many cases the PSAP’s serve only as an initial contact point and transfer calls to secondary centers where the emergency response units are actually dispatched.

There is, however, no directory of these secondary dispatch centers available, so the research team obtained information about the emergency departments served by selected PSAP's and attempted to contact the secondary EMS, fire, and police dispatch centers directly. This effort did improve the response rate.

2 Survey results

2.1 Summary survey results

We received a total of 54 survey responses from agencies in both urban and rural areas. The sample size was deemed acceptable to draw conclusions. Responses to selected questions, particularly those that relate to the impacts of congestion on emergency response, are discussed in the following sections. Most of the results have been summarized according to whether the agency serves a predominantly urban or rural area. This distinction was made because traffic congestion impacts urban and rural areas differently and we expected there might be differences in how congestion is perceived in each.

2.1.1 Training

100% of respondents stated that they have received some type of training to prepare them to serve as dispatchers, but less than a quarter reported that they have received training specifically on ways to cope with traffic congestion. This was true in both urban and rural areas.

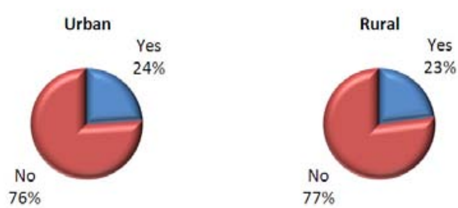

Figure 1: Have you received training to cope with traffic congestion?

2.1.2 Use of computer aided dispatch systems (CAD)

Respondents were asked whether their agency uses a computer aided dispatch (CAD) system. This is important because most CAD systems have the capability to incorporate real-time traffic information into the dispatch process. 81% of the agencies serving urban areas and 74% of those serving rural areas indicated that they use a CAD system. However, none of the respondents surveyed in either urban or rural areas said that their CAD system currently incorporates real-time traffic data into the dispatch process.

2.1.3 Impacts of congestion

Dispatchers were asked how often emergency vehicles in their jurisdiction are impeded by traffic congestion. 52% of urban dispatchers and 42% of rural dispatchers responded "Some of the time". Perhaps more interesting, 48% of urban and 54% of rural dispatchers responded that traffic congestion rarely or never impacts vehicle response times. The data were checked to see whether these respondents worked primarily on shifts where traffic levels are typically low (e.g., overnight). It was found that overnight shift workers accounted for half the “Rarely” responses in urban areas and 20% of the “Rarely” responses in rural areas.

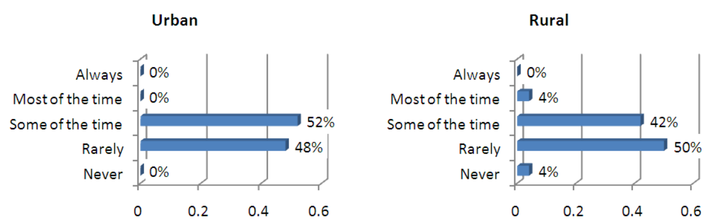

Figure 2: How often are emergency vehicles impeded by traffic congestion when responding?

2.1.4 Is congestion perceived as a significant problem?

When asked if they view traffic congestion as a significant problem that contributes to increased response times, only 33% of urban dispatchers and 31% of rural dispatchers have said that they “agree” or “somewhat agree”. In fact, 48% of urban dispatchers and 50% of rural dispatchers said that they “disagree” or “somewhat disagree”.

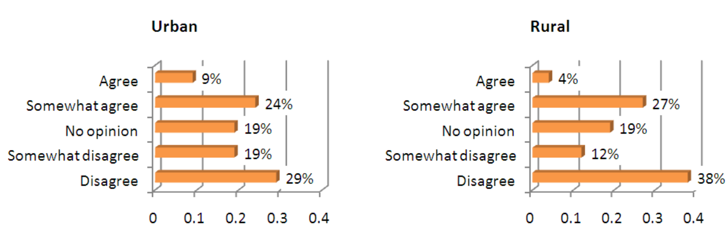

Figure 3: Traffic congestion is a significant problem that causes increased emergency response times (all respondents).

The data were checked to see what portion of the latter responses came from dispatchers who worked primarily overnight or weekend shifts when traffic volumes are typically lower. When these respondents were removed from the sample the distributions shown in Figure 4 were computed. Still, only 40% of weekday dispatchers responded “Agree” or “Somewhat Agree”, while for rural dispatchers the percentages was 37%.

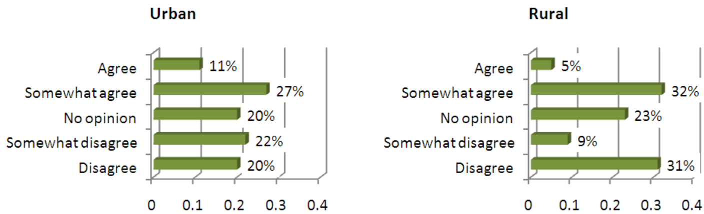

Figure 4: Traffic congestion is a significant problem that causes increased emergency response times (weekday morning and afternoon shifts only).

2.1.5 Consideration of traffic conditions when dispatching

Dispatchers were asked if they consider traffic conditions when selecting a vehicle to dispatch. In both urban and rural areas only about 15% replied that they do. The most likely reason is that the dispatchers do not have access to real-time traffic information in the dispatching centers.

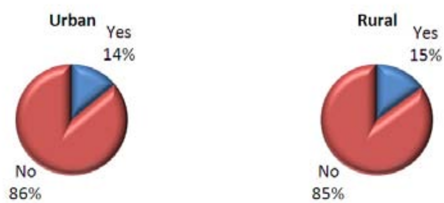

Figure 5: Do you consider traffic conditions when selecting a vehicle to dispatch?

2.1.6 Availability of real-time traffic information in the dispatch center

None of the 54 survey respondents reported that they had access to real-time traffic information in the dispatch center. This is consistent with the interviews we held with local dispatchers, who stated that the dispatchers are largely unaware of existing traffic conditions and congestion. The primary source for traffic information appears to be information relayed by the emergency responders in the field.

2.1.7 Would real-time traffic information be helpful to dispatching?

Dispatchers were asked if having access to real-time traffic information in the dispatch center would be helpful to the dispatching process. 72% of urban dispatchers responded that it would be "very helpful" or "helpful" and 54% of rural dispatchers said the same.

2.1.8 Do dispatchers alert emergency units to congestion in their area?

Dispatchers were asked whether they ever alert emergency units to congestion in their area. Despite the fact that none of the respondents said they have access to real-time traffic data, over 50% of dispatchers said that they do, at least on occasion, alert units in the field to traffic congestion in their vicinity. Based on other survey results, it is assumed that most of this information is provided by other units in the field.

2.1.9 Quality of information provided by 9-1-1 callers

In interviews emergency responders expressed some frustration with the quality of information provided by dispatchers, both with respect to the location and nature of emergencies. Dispatchers indicated in interviews that they are usually just relaying information provided by 9-1-1 callers and cannot always verify its accuracy. The survey asked dispatchers to rate the accuracy of information provided by 9-1-1 callers. The responses show that over 75% of respondents stated that they either 'agree' or 'somewhat agree' with the statements that the information provided 9-1-1 callers regarding the location and nature of emergencies is accurate. Less than 20% answered 'somewhat disagree' or 'disagree', reflecting general confidence in the information provided.

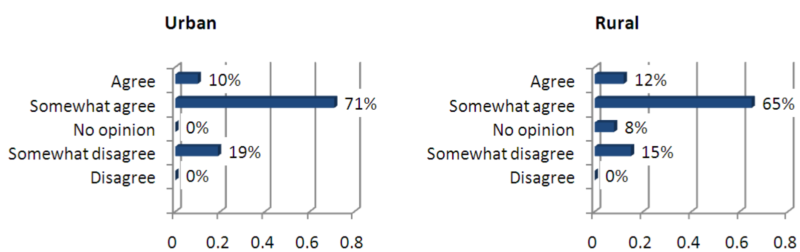

Figure 6: Callers to 9-1-1 provide accurate information concerning the *location* of the emergency.

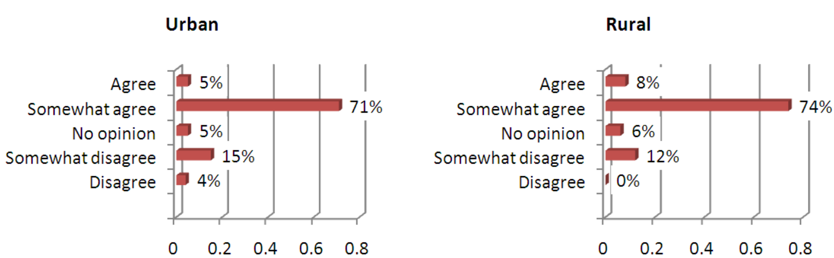

Figure 7: Callers to 9-1-1 provide accurate information concerning the *nature* of the emergency.

2.1.10 The role of education on emergency response times reduction

Dispatchers were asked whether they believed public education about how to provide accurate information to 9-1-1 call takers and emergency dispatchers would help to decrease response times to emergency scenes. Despite the fact that they generally felt that the public provides accurate information, 100% or

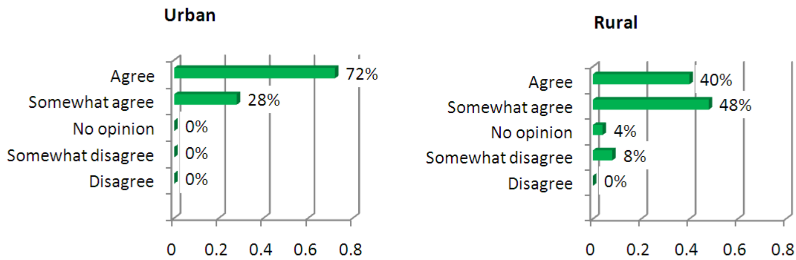

Figure 8: Public education about how to provide accurate information to dispatchers would help to decrease response times to emergency scenes.

urban dispatchers and 88% of rural dispatchers either ‘agreed’ or ‘somewhat agreed’ that some type of public education could help reduce response times.

2.1.11 Impacts of automatic crash notification systems on response

Dispatchers were asked whether they felt automatic crash notification systems such as On-Star would have a beneficial effect on the timeliness of emergency response. Large majorities of both urban and rural dispatchers felt that it would.

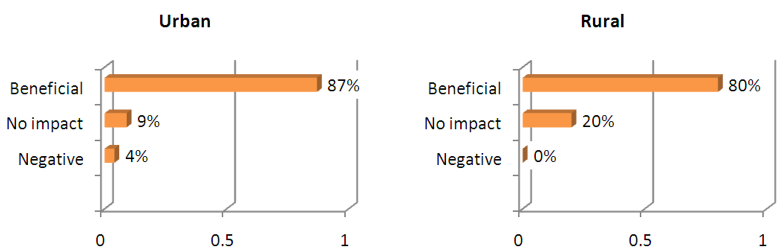

Figure 9: Do you feel that Automatic Crash Notification systems (e.g., OnStar) have a beneficial, negative, or no impact on the timeliness of EMS response?

2.1.12 Accuracy of cell phone location information

Dispatchers were also asked whether 9-1-1 caller location information provided by cell phone companies is accurate. In interviews, some dispatchers had expressed frustration with the quality of the cell phone location data provided. At times the location information was inaccurate or merely provide the location of the nearest cellular tower. This concern was confirmed in the survey, more so among urban dispatchers, 62% of whom said that cell phone location information is correct only some of the time or rarely. By contrast, 60% of rural dispatchers said cell phone location information is accurate always or most of the time.

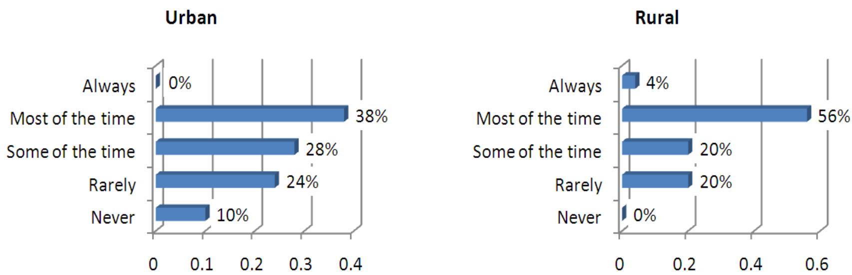

Figure 10: When the caller is using a cell phone, the location information provided by the cell phone carrier is accurate.

2.1.13 Training for large-scale emergencies

The survey also asked dispatcher whether they have received training to deal with large scale emergencies (e.g., natural disasters or evacuations) and whether their agency drills/trains for such emergencies. The response in both urban and rural areas was that most agencies do train and practice for large scale emergencies.

2.1.14 Suggestions for improving dispatching

Dispatchers were asked to name two enhancements they felt would most enhance their current dispatch processes. The most commonly suggested enhancement was the deployment of automatic vehicle location systems (AVL) which would allow dispatchers to track the location of units in the field. Other common suggestions included improved caller location information for both cell phone and voice-over-IP (VOIP) systems, more efficient call transfers from the 9-1-1 centers to the secondary agencies, and consolidating police/fire/rescue dispatch systems. Rural dispatchers also cited the need for better CAD systems and installation of mobile data terminals in the response units. Having real-time traffic information available in the dispatch center ranked very low in both urban and rural agencies. Traffic congestion was generally not viewed as a major concern among the dispatchers surveyed.

Table 1: Suggested enhancements (most suggested to least suggested).

Urban Dispatchers	Rural Dispatchers
Automatic Vehicle Location (AVL)	Automatic Vehicle Location (AVL)
Better 9-1-1 call transfer	Consolidated fire/police/rescue dispatch
Improved caller ID for VOIP services	Improved caller location for cell phones
Improved caller location for cell phones	Mobile Data Terminals in vehicles
Consolidated fire/police/rescue dispatch	Better CAD system
Public education	Better 9-1-1 call transfer
Better CAD system	Improved training
Improved training	Improved caller ID for VOIP services
Multi-jurisdictional 9-1-1 Center	More dispatchers
Real-time traffic information	Real-time traffic information
Upgraded equipment (general)	More dispatchers

3 Discussion and study conclusions

3.1 Summary of results related to traffic congestion

The survey results lead to several interesting conclusions as they relate to traffic congestion and emergency response:

- A majority of dispatchers, even those who work during peak traffic periods in urban areas, do not perceive traffic congestion to be a significant problem that causes increased emergency response times. Over 90% of dispatchers said that emergency vehicles are impeded by congestion only 'some of the time' or 'rarely'.
- None of the dispatchers who responded to the survey have access to real-time traffic information in their dispatch center. Only about 15% of dispatchers say that they consider current traffic conditions when dispatching a vehicle.
- A majority of dispatchers agreed that having access to real-time traffic information would be helpful to the dispatching process. 72% of urban dispatchers felt it would be helpful to take under account real traffic conditions when making dispatching decisions.
- The improvements dispatchers felt would most benefit the dispatching process related to:
  - In-vehicle equipment such as automatic vehicle location (AVL) systems so that they can better track units in the field,
  - Improved coordination between dispatching agencies, in particular smoother transfer of calls from primary 9-1-1 call centers (PSAPs) to secondary dispatch centers, and
  - Improved accuracy for the location of 9-1-1 callers, particularly those using cell phones and voice-over-IP (VOIP) services.
- Access to real-time traffic information ranked low on the list of improvements most commonly recommended by dispatchers. Addressing traffic congestion does not appear to be a high priority for most dispatching agencies.

The reported lack of access to real-time traffic information was not unexpected, given that there is currently limited real-time traffic information available in Alabama. The systems required to collect and disseminate that information are only now being brought on line and if dispatchers do not have access to real-time traffic information they are less likely to perceive congestion as a problem. The broader concern for this study is that dispatchers do not have access to either information or systems that would allow them to manage a large scale emergency that involve severe traffic congestion or congestion over a broad area and this may inhibit their ability to minimize the emergency response time to an incident site.

3.2 Comparison to the results of the emergency responders survey

The design of the modern, centralized dispatch center offers many benefits in terms of improved communication and cooperation among response agencies. However, one issue that still remains unresolved is the disconnect between dispatching decisions and conditions in the field. The full results of the emergency responder survey (also being performed under the UAB UTC) have not yet been published. There are, however, preliminary results available that allow us to make some comparisons.

- While approximately 60% of emergency responders reported that they encounter traffic congestion during an emergency call only 'sometimes' or 'rarely', over 90% of dispatchers believed that responders encounter congestion only 'sometimes' or 'rarely'. This would indicate that congestion is a more common issue than dispatchers are aware.
- Only 12% of emergency responders reported using Alabama Department of Transportation (ALDOT) web-cams for information on traffic conditions and just 7% of dispatchers reported the same.
- 50% of dispatchers in urban areas and over 60% in rural areas report that they have provided information in congestion to units in the field. However, only 28% of emergency responders stated that they have received congestion information from a dispatcher.
- Similar percentages of dispatchers and responders (about 86%) felt that automatic crash notifications systems such as On-Star will help to reduce emergency response times.

Documentation of perceptions and practices of emergency services dispatchers in Alabama provided useful insights on current practices, positive and negative experiences, preferences, and perceptions on the use of real time traffic data to help optimize emergency response and transport times. The results of the survey analysis clearly show that dispatching decisions do not consider traffic conditions in the field. To improve current practices and procedures real-time traffic information should be come readily available to dispatchers in the near future. Moreover, education of dispatchers about the opportunities and benefits that can be realized by considering traffic congestion presence in the dispatching process can help improve EMS performance and reliability, which in return can improve survivability of victims requiring medical attention at incident sites.

Acknowledgements

This paper is based on work funded by the Research and Innovative Technology Administration (RITA) - U.S. Department of Transportation (US DOT) through the UAB University Transportation Center. The authors gratefully acknowledge the support from these sponsors.

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How can the risks associated with climate change help shape Lord Howe Island fire management planning

M. J. Beltran
Sydney University, NSW Rural Fire Service, University Western Sydney, Australia

Abstract

Lord Howe Island is the most geographically isolated community within the State of New South Wales, lying 600 kilometres east of the Australian mainland in the Pacific Ocean. Apart from the small resident and tourist community the Island boasts an environment that was unseen and therefore untouched by man until the colonisation of NSW but now has numerous threatened and endangered species, some unique to the island.

The Island's climate, with its maritime influence, has to date ensured a very low wildfire risk (and the predominantly natural vegetation communities are susceptible to fire) however, weather records for the Island indicate a small but perceptible temperature increase over the last 50 years and to date there have been isolated periods of unusually low rainfall. Climate anomaly and weather variability may increase fire risk factors for the Island and these are warning signs of a potential increasing exposure to destruction of habitat and threat to residents and visitors.

In an overarching environment where local history indicates that there is a negligible wildfire risk and where the local administration faces considerable competition for its financial and physical resources, the challenge for fire management practitioners is in creating reasonable argument to substantiate potential unseen and previously unknown risk and thereby create an awareness that is adequate to trigger an increased preparedness with community awareness and fiscal and resource planning.

This paper analyses the various State and Commonwealth policies in play for climate change in an emergency management context, the current and potential

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110131

fire risk management factors, and the challenges facing a small, isolated community in adopting new, different, radical and controversial concepts.
Keywords: risk, climate change, fire management planning, climate anomaly, weather variability, emergency preparedness, community, Lord Howe Island.

1 Introduction

Lord Howe Island (*the Island)* was spared the hand of man until 1788 when the first incursions and interference with its natural order occurred. Whilst the effect of human interference has resulted in the extinction of nine species and the 'endangered listing' of several others, today the Island remains blessed by its natural endowments and the small resident population works hard to keep it clean and green, worthy of its World Heritage status.

Fire is a natural enemy of the Island and its effects, in any other than the most rigorously controlled 'management' uses, will socially, economically and environmentally affect the resident and visitor populations, biodiversity and landscape in some form. At its extreme, fire may have uncompromising and permanently deleterious results.

Not only does the tyranny of distance over ocean add to the cost burden of the fire combat and recovery effort but the ramifications for a small community in terms of social and economic impact can be serious. A recent fire in the Island's power station proved this point. Of course it is hoped that fire will never be the agent of further demise of the Islands unique natural habitats.

Although the effects of climate change still remain unquantifiable in terms of the Island's future, there is a probability that weather events may deviate from the historical averages and that trends of increasing temperatures coupled with possible dry spells may expose the Island environment to increasing wild fire risk.

Lord Howe Island is the most geographically isolated community in NSW. Positioned in the Pacific Ocean approximately 600 kilometres east of Port Macquarie it can only be accessed by sea or air, and both forms of transport are subject to the dictates of weather.

The Island is anomalous in NSW governance; it functions within the NSW system as a distinct and unique bureaucracy/public administration in the form of the Lord Howe Island Board (the Board), which reports to the Minister for Environment, Climate Change and Water. The Island is subject of special legislation, The Lord Howe Island Act 1953, Amended, which gives the Board similar authorities to local government in NSW, and importantly gives it responsibility as the land manager for the Island group (inclusive of the Admiralty Islands, Ball's Pyramid, Blackburn Island, and the adjoining islets). It manages all land, totalling about 1455 hectares, and there is no private land ownership, only leases for which the Board has authority. The small resident community (353 according to the last ABS census) is broken into two groups – the first being those related to earlier settlement of the Island, and the second being those others who are engaged in the Islands administration and businesses.

The Island has the benefits and limitations of human and physical resources expected of a community and bureaucracy of its size, type and isolation.

For the NSW Rural Fire Service (the Service) this difference in governance may explain why, until now, it has simply concentrated on the maintenance of the Island's Rural Fire Brigade, in the forms of training and equipment, but has not progressed with the application of its statutory and other related programs.

There are, though, several compelling reasons to concentrate on the delivery of these government policies in order to strengthen the capacity and resilience of the Island and climate change risk is a prominent reason. There is currently both a challenge and an opportunity for the RFS in complementing the development and delivery of its programs at the Island, with consideration of the possible effects of climate change as enhancements to these programs.

'Fire Management Planning' is a term used to describe a combination of Service statutory and program measures packaged to enhance the process of fire management on the Island. The planning/program matters include the statutory 'Bushfire Risk' [1] and 'Operations Management' Plans (Section 52 of the Rural Fires Act 1997), the Service's 'Standards of Fire Cover' and 'Brigade Classification' programs, a 'Mainland Rapid Response' plan, and forward budget advice. The 'Mainland Response' plan is a unique concept floated especially to address the Island's predicament of isolation and limited resources. The concept of a forward estimate is proposed so as to prepare all parties for financial contribution to equipment or operational requirements that will likely exceed current and historical levels of financing (this affects the Island Board, the Service, the insurance industry and the NSW Government).

Research demonstrates that the fire history (both wildfire and structural fires) of the Island records little fire activity throughout its settled history; the Island was first visited by humans in 1788 and has been settled since then. This relative lack of fire activity (in totality for the Island, and certainly in comparison to the mainland where the use of fire by the traditional owners has helped shape the environment) coupled with the fact that the Island has a sub-tropical characteristic (which naturally lessens fire risk), helps to generate a cultural perception that the Island environment is wildfire resistant, and in some minds, perhaps, even that it has no wildfire threat.

Climate change is recognised as a phenomenon that will progressively threaten and challenge the world's communities and environments. The seriousness of this risk is resonating within the public domain, and climate change treatment is prominent within public policy, as is reflected by the following:

- The NSW Government advises that climate change planning is a State policy [2] (NSW Greenhouse Plan, page 24) "The NSW Government aims to minimise the impacts of climate change through adaptation measures",

The Australian Commonwealth Government [3] pledges that (Australian Greenhouse Office, Climate Change Risk and Vulnerability, Promoting an efficient adaptation response in Australia, 2005, page viii)

- "…adaptation strategy will aim to increase the resilience of human and natural systems to possible changes in climate conditions…", and,

- The Council of Australian Governments (COAG) [4] promotes positive action (Council of Australian Governments' Plan for Collaborative Action on Climate Change, COAG meeting 10 February 2006, Attachment C, page 1.) "…early action to prepare for this change will minimise costs to our community".

It is generally recognised that climate change will have effect within NSW communities on the fundamental factors that contribute to the occurrence and impact of fires and other emergencies. This is a Service position, anchored in NSW Government (Greenhouse) policy and action. Factoring climate change into the Island's fire management planning is a tool that has two complimentary facets. The first is of course one that adds value to the risk analysis for both the natural and built environment. The second resides in the nature of the changing climate as a 'thought provoker', 'image maker', and 'demanding of action' within the broad community and especially amongst those carrying civic authority. The promotion of climate change risk as an adjunct to fire management planning (in the context of the Island's lack of significant fire history) should greatly assist in driving home the notion that there may be significant potential risks for the Island's communities. Risk management principles provide the tool to look beyond local historically focused prejudices to consider new aspects of 'likelihood' aligned to 'consequence' as the means to measure the impact of events or scenarios.

2 Fire management frameworks

The Service provides NSW with statutory and policy programs that create and complement the public safety mantle of measures through preparedness, prevention, recovery and response to emergencies and disasters. These planning measures are generally based upon current risk trends and fire histories, (you will recall that the Island has little fire history and little acknowledgement of current threat trend) but by defining those elements of climate change risk that impact on fire management it becomes possible to promote insights into future risk.

The genesis of the project question comes from experience with the effect of weather variables and short term climate variation. Weather variables in terms of fire danger prediction and wild fire behaviours are those very factors that make one day or period more fire dangerous than those before or after. As fire is dependent on three variables – heat, fuel and oxygen (the 'fire triangle') – the weather elements of temperature, relative humidity and wind strength (and of course fuel load) are all critical factors of wildfire existence and basic behaviour.

Fire fuels within natural environments are generally static within short time periods, but are constantly subject to weather conditions and effects that may at any time add considerably to that fuel load (e.g. very hot and/or dry periods have an effect on eucalypts in that they naturally shed leaves in these conditions, and very strong wind gusts may break branches from trees). For anyone with experience, or perhaps knowledge, of Australian summertime conditions, it comes as no surprise that prevailing weather conditions applied to woodlands and grasslands provides a natural recipe for fire to thrive. Wildfire is accepted as being a natural component of the Australian environment, but rainforest is obviously not so readily available to fire (because of the generally prevailing high fuel moisture content, the higher prevailing relative humidity, and because the predominantly closed nature of the forest prevents wind penetration). In fact, whilst much of Australia's flora is fire dependent or fire tolerant, rainforest is fire intolerant.

Although the existence and passage of wildfire in rainforest is uncommon, it has been experienced in NSW and otherwise by the Service. For example, wildfire burning within the forests of the Blue Mountains (The Lawson's Long Alley S44 fire emergency, November 2006, is a good example of wildfire burning unimpeded by rainforest belts) has on occasion, when the drought factors have been high, progressed through rainforest belts which would in other, 'normal' seasons stopped or significantly slowed this wildfire. Another poignant example for the Service was in its assistance to the Malaysian Government in preparatory planning for assistance with wildfires burning in the jungles of Sarawak, Borneo, prior to its Commonwealth Games (The Commonwealth Games were held in Kuala Lumpur in 1998). This example demonstrates that even rainforest of equatorial status burns during pronounced drought. It is important to note at this juncture that fire prediction models have been developed in Australia for eucalypt forest and grasslands, but not for rainforest.

The foregoing supports the notion that if equatorial jungle (as in the Sarawak example) or cool temperate rainforest (as in the Blue Mtns example) can be the subject of wildfire brought about by climatic anomaly, then the mid latitude rainforest of the Island can equally be exposed to fire risk brought about by weather variation/climate change. In judging fire risk and operational constraint, the Island has a plentiful (dormant) fire fuel potential, operationally difficult terrain and the quandary of limited resources and difficulties with logistical back-up/supply (i.e. over distance and via air or sea).

3 The literature review

The literature review demonstrates that there is an amount of published knowledge and hypothesis about the general trends and predicted effect of climate change for mainland Australia, some specifically commissioned for NSW. However, beyond agreement within the scientific community that a global rise in sea level will affect the Island (as it will coastlines and tidal reaches globally), there is as yet no common scientific opinion on climate change factors as they may affect the Island.

There are references to climate change risk within both the Board's Biodiversity Management Plan [5] and the NSW Dept of Climate Change (DECC) Lord Howe Island Permanent Park Preserve Draft Plan of Management [6]; both of these plans deliberately (albeit very minimally, but critically) rate climate change risk potentials as noteworthy.

In terms of data and/or information that is available to construct or inform primary research, the following was valuable:

* The Bureau of Meteorology has measured and collated daily weather readings on the Island since 1886
* The NSW Bushfire Co-ordinating Committee's (BFCC) Policies on 'Bush Fire Risk Planning' and 'Operations Management Planning'
* The spatial information suite held by the Board that contains terrestrial and vegetative data
* Demographic and resource data held by the Board
* Board policy
* Service policy

The Service's Risk Matrix provides a basis by which to measure the potential impacts of the consequence and likelihood of risks, and thus assign a degree of importance of treatment of the risk. The BFCC guidelines cover 'consequence ratings' and 'likelihood ratings', and are of considerable assistance in posing these questions:

1. What is a likely fire frequency? And,
2. If a fire occurs, what are the likely consequences to the natural and/or built environment?

DECC prescribes threat treatment directions which can readily inform the development of the bush fire risk management plan, however, with direct reference to the philosophy of 'natural ecological and land forming processes…being allowed to continue without human interference', there is potentially some conflict with the 'fire management strategies'; this ambiguity demands careful consideration in the development of the fire management Operations Plan. DECC also relates to the 'elimination of trees' on Blackburn Island (part of the Island group), in part to fire, which adds credence to the notion the fire is destructive in at least part of the Island's ecological mix.

The BFCC guideline further calls for information on climate for treatment areas, for which the Aust. Bureau of Meteorology (BoM) data offer weather record statistics for the Island. As bushfire risk is tied to weather variables and available fire (vegetation) fuels, an understanding of the potential for climate change to alter either or both of these factors enables risk assessors to consider potentials beyond historical and contemporaneous limits. DECC further highlights the importance of this factor with a simple reference that climate change may have adverse impact in terms of possible drought, thus inexplicably linking to a key fire danger element.

4 Climate change and fire risk

There are already manifestations of a changing climate on the Island. By conducting a comparative analysis of weather data from the BoM's weather station on Lord Howe Island, there is a demonstration of a trend, over time, that the mean maximum and mean minimum monthly average temperatures experienced by the Island have risen. Temperature rise is a benchmark of global warming and an indicator of climate change. This trend is depicted by the following graphs:

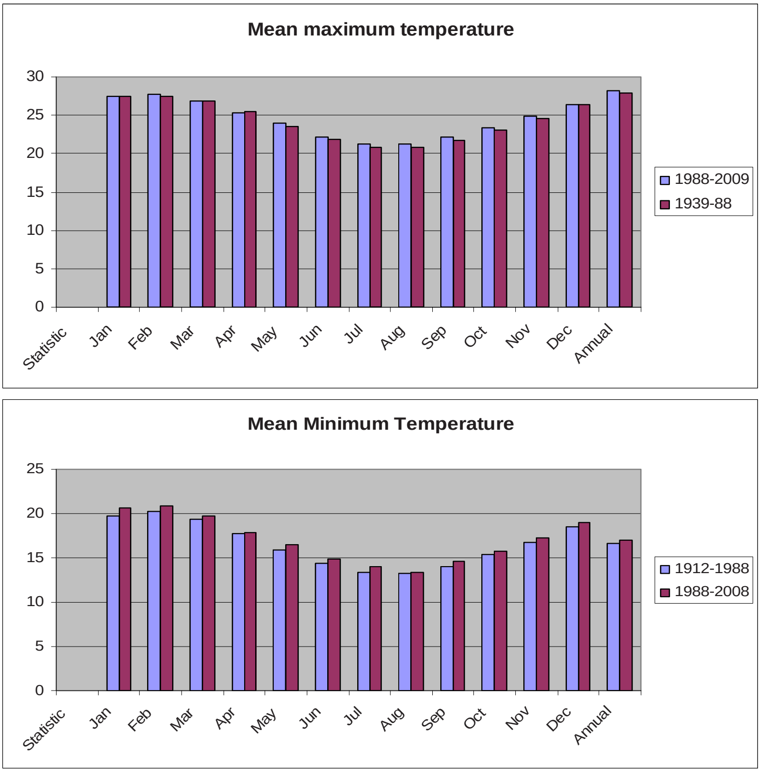

Figure 1: Temperature comparison graphs for Lord Howe Island.

In relation to the comparative time periods, whilst it has been demonstrated the there has been a general trend to rising temperature, the most significant factor was that in regards to the mean maximum temperature readings, that in the 1939–1988 grouping the maximum reached was 29ºC, whereas in the 1988–2008 grouping the maximum reached was 31.3ºC, a rise in single event terms of 8%. Temperature, you will recall, has a critical significance in wild fire prediction modelling. This questions the potential for future maximum temperature states.

In a report that Professor Ross Bradstock, University of Wollongong, presented to the Service (29/05/09) on climate change and bushfires, he spoke of irregularities in rainfall, i.e. periodic (non regular) drought or dry spells, as being a most significant factor in the development of serious fire dangers in forests. The indication is that the regularity of rainfall will be a victim of the changing climate.

The Board has provided information on seasonal rainfall experiences, inclusive of data that demonstrates the irregularity of rainfall and the irregular incidence of relatively dry summer periods. Over time, the Island has been challenged by these irregular dry spells, albeit that these have to date been of short duration (limited to a month or so). A comparative table demonstrating 20^{+} years follows.

Table 1: Rainfall records for Lord Howe Island, showing the occurrence of months with less that 50mm of rainfall for a month, as well as the highest rainfall records (shown shaded) for each of the months within the period.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2010											14	
2009	43			515	48					44	15	25
2008			17									
2007	18	37						22.4				
2006		21									49	
2005		30			322		208					
2004											35	
2003									45			
2002											29	
2001	35		290								286	
2000		5	38									
1999												
1998		524								230		
1997	41	34		43						49	27	38
1996	480					562						40
1995		39						41				
1994		26										
1993				34					166			
1992												
1991										27		245
1990								286				33
1989		30										

This monthly rainfall record (1989–2010) demonstrates an erratic pattern of rainfall for the Island; note however that some months have recorded very low rainfall, as low as 5 millimetres (February 2000). Note that during this period there have some relatively dry spells of consecutive months.

As previously referenced, forest fuel moisture content and grassland curing, both the subject of (the lack of) rainfall, have critical significance in wildfire prediction modelling. Given that the BoM statistics also confirm that the Island is regularly the subject of winds of strength, we already have a confluence of fire weather features (temperature, dryness and wind). This demonstrates possibilities for elevated wildfire risk given the known climate change trends of temperature rise, coupled with the possibilities of the Island suffering drought (DECC Lord Howe Island Biodiversity management Plan, ‘Potential threats’, page 32) [5] and with the ever present possibility of strong, steady wind.

One of the weather factors that make any environment less prone to the risk of serious fire is high relative humidity – it essentially works as a cooling agent by adding moisture to fire fuels. BoM records demonstrate that relative humidity on the Island is predominantly above 50%; thus adding to the general belief that there is little prevailing fire danger there. The weather readings are however taken near sea level, and, apart from the work that DECC is currently undertaking at and near the summit of Mt Gower, there is still the question of relative humidity differing due to elevation or Island environments.

This was tested in a simple field experiment which measured temperature and humidity across landscape and within forest environments, conducted on the Island on 10th May 2009, using a Kestrel portable weather meter along the Goat House Cave track, as follows:

Table 2: Humidity over elevation and terrain study, Lord Howe Island.

Place/elevation	**Temp ºC**	**Humidity %**	**Barometer**
Soldier's Ck, 17m	20.2	54.6	1014.3
76m	17.6	55.7	1006.8
127 (saddle)	17.3	49.7	1006.6
146	18.1	51.9	998.6
182	17.8	45.9	994.4
212	19.2	49.2	990.8
229 (Creek crossing)	18.4	48.7	989.0
266	18.1	49.8	984.7
322	18.6	53.3	978.3
367	19.2	53.6	972.7
407	18.4	49.6	968.2
442	22.5	47.4	964.1
452 (Goat House Cave)	19.8	44.9	963.2
235 (Creek crossing)	19.7	47.1	988.1

As previously stated, this was a very simple test, but it did demonstrate variables of temperature and humidity across the landscape. The differences in humidity readings in the Goat House Cave track environment were substantial.

Another pertinent question relates to the effect of ENSO [7] (the El Niño Southern Oscillation) on the Island; does the Island parallel the mainland in the manifestation of droughts (El Niño) and floods (La Niña). A comparative analysis of ENSO readings and Island rainfalls for two four year blocks 1997–2000 and 2005–2008 revealed no discernable correlation between ENSO and the Island's precipitation patterns.

These two four year blocks were chosen because they contain some pronounced positive and negative sequences. One notable outcome from this study is that, as yet, there is nothing to suggest why the Island has had the serious dry spells that it has occasionally suffered, and thereby denying forecasters a prediction tool by which to prepare for, and mitigate against, fire weather periods.

5 Programs and policies

The Service has begun the facilitation of a Fire Management Planning suite for the Island that necessitates the engagement of the Service and the Board (and other players dictated by role as prescribed by the NSW Bush Fire Co-ordinating

Committee) to develop robust and co-operative arrangements to mitigate against and minimise unwanted fire.

The Bush Fire Risk plan, in particular, will have an impact for the protection of the Island's people and its built and natural environments by the identification of special and specific risk areas. The Operations Management plan will ensure the co-ordination of the emergency responders and land management authority into a co-operative response community. The Service's other programs of standard of fire cover and brigade classification will ensure that appropriate resourcing levels are agreed and that the Island's fire responders are suitably equipped for their role.

The requirement to ensure that this plan links to and complements the Board's plan of management of the Permanent Park Preserve and the Biodiversity Management Plan is obvious. Although anthropogenic climate change is listed as a Key Threatening Process (The Biodiversity Management Plan, pages 20–31, lists 15 Key Threatening Processes) for the Island's biodiversity, further consideration to listing wildfire to this grouping may be warranted.

6 Conclusion

The primary conclusion is that the Island is potentially the subject of weather anomaly/climate variability that could present the onset of unprecedented and largely unexpected fire dangers to the built and natural environments. Given the issues of the Island's geographic isolation, the limitations of its resources, the nature of the Island's unique natural environment and the criticality of early fire detection and rapid suppression, it is important that fire planning measures are targeted and robust and that climate change potentials are captured in the risk analysis. The Service's work with the Risk Management and Operations Management Plans are key first steps to this goal.

The very factors that affect this small, isolated and precious environment are undoubtedly at play at many other such rare locations around Australia and the world and it is important that any emergency planning systems that use historical trend factors of weather and incident occurrence as trusted, perhaps sole, benchmarks for program development bear in mind the radical short duration variables that climate variation can produce.

Co-operation between governments, administrations and authorities is crucial to meeting the challenges of emergency management, especially in a climate change context, with the potentials for development of monitoring systems, fiscal and administrative perspicacity inclusive of knowledge sharing and joint research arrangements, and the refinement of rapid emergency response systems inclusive of pre-deployment in sensitive situations.

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Catastrophic failure planning for the SR 520 bridge

G. MacDonald[1], D. Babuca[2], A. Swanson[3], T. Lentz[4] & P. Scalingi[5]
[1]*Parametrix, Bremerton, Washington, USA*
[2]*Washington Department of Transportation, Seattle, Washington, USA*
[3]*EnviroIssues, Seattle, Washington, USA*
[4]*Parsons Brinckerhoff, Seattle, Washington, USA*
[5]*Pacific NorthWest Economic Region, Seattle, Washington, USA*

Abstract

The State Route 520/Evergreen Point Floating in Seattle, Washington, is vulnerable to windstorms and earthquakes and needs to be replaced. The Washington State Department of Transportation (WSDOT) recognizes the need to have a plan in place to manage traffic and communications if the SR 520 floating bridge were lost in such an event. The plan was developed in collaboration with regional jurisdictions, transit agencies, emergency responders, and businesses, as a toolkit of strategies that could be implemented quickly and effectively to benefit the region. WSDOT also invited engineers from Minnesota DOT to contribute to the plan by sharing their experience from I-35W bridge collapse and recovery. The main components of the plan are the Transportation Management Plan and the Communications Plan. A regional tabletop exercise focusing on a SR 520 catastrophic failure scenario helped to inform the development of the plan. The SR 520 Catastrophic Failure Plan provides a basis for WSDOT to prepare for a catastrophic bridge failure and for local jurisdictions to develop their own emergency response plans.
Keywords: catastrophic failure plan, transportation management, communication, tabletop exercise, floating bridge, disaster preparation, bridge failure.

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110141

1 Introduction

Seattle, Washington is bounded by the Puget Sound on the west and Lake Washington on the east. State Route 520 (SR 520) is one of only two east-west links across Lake Washington and is a vital regional transportation corridor of both people and goods. The SR 520 floating bridge currently carries approximately 160,000 people and 115,000 vehicles per day [1]. Construction of SR 520 was completed in 1963 and touts the world's longest floating bridge. The aging SR 520 bridge and approaches are vulnerable to both windstorms and earthquakes, and are nearing the end of their useful lives [2]. If the SR 520 bridge were to fail, the effects to regional and statewide travel and economy would be significant.

The Washington State Department of Transportation (WSDOT) is committed to catastrophic failure planning to ensure public safety and a speedy recovery in the event of a catastrophic loss of the SR 520 bridge. In coordination with transportation, communications and emergency response professionals from regional jurisdictions, transit agencies, businesses and community organizations, WSDOT has developed a catastrophic plan to lay out steps state and local agencies may take to manage traffic and communications should such an event occur. The plan consists of a transportation management plan and a communications plan [3].

1.1 Keeping the Seattle Regional Area moving

The overarching goal of the catastrophic failure plan is to identify strategies to keep people and commerce moving in and around the Seattle and surrounding cities (also known as the central Puget Sound region) in the event of a SR 520 bridge failure. The catastrophic failure plan builds upon established WSDOT SR 520 emergency management procedures. It represents a toolbox of strategies that can be implemented to keep central Puget Sound drivers and commerce moving during a long-term recovery from a SR 520 bridge failure.

The transportation management plan provides WSDOT, local jurisdictions and transit agencies with transportation strategies designed to ease traffic congestion resulting from the failure of the SR 520 bridge. The communications plan will support emergency response, bridge recovery and bridge restoration efforts through development, coordination and dissemination of emergency public information. See Figure 1 for the focus area for the SR 520 bridge catastrophic planning efforts. The figure also identifies the jurisdictions that coordinated with WSDOT during the planning.

1.2 Current WSDOT activities that support the catastrophic failure plan

WSDOT is currently in the process of the design and construction of a replacement bridge and adjoining highway segments. The purpose of the SR 520 Bridge Replacement and HOV Project is to increase safety and reliability of the highway and bridge. Elements of the SR 520 Bridge Replacement and HOV Project support the catastrophic failure plan. These include:

- **SR 520 Pontoon Construction Project**—This project advances pontoon construction in hopes of restoring the floating section of the SR 520 bridge before a catastrophic failure event occurs.
- **Accelerated SR 520 project schedule**—In response to the Washington State Governor's request, WSDOT identified ways to shorten the overall project schedule. The acceleration will result in opening the new bridge to traffic in 2014. This will result in closing the window of vulnerability for a potential catastrophic failure.

1.3 Developing the catastrophic failure plan

The SR 520 Bridge Replacement and HOV Project team continued to work with jurisdictions and transit agencies to facilitate a coordinated response to a potential SR 520 bridge failure. The intent was to develop a comprehensive list of potential strategies and improvements for WSDOT highway facilities that could get the central Puget Sound region moving again and could aid in the long-term recovery process. The SR 520 project team developed a three-pronged approach to prepare a catastrophic failure plan:

- Conduct a tabletop exercise.
- Develop a transportation management plan.
- Develop a communications plan.

In a final step, the transportation management plan and the communications plan were merged into the catastrophic failure plan.

2 Tabletop exercise and action strategy workshop

The SR 520 project team prepared plans for a tabletop exercise that would help inform a catastrophic failure plan. The resulting transportation management plan and communications plan seek to address findings of the tabletop exercise action strategy workshop.

2.1 Tabletop exercise

WSDOT hosted a day-long tabletop exercise with local jurisdictions, businesses and other key stakeholder organizations to examine preparedness, response and longer-term recovery issues associated with a SR 520 bridge failure. The goals of the exercise were to:

- Raise awareness of vulnerabilities and risks to the bridge.
- Identify response and longer-term restoration needs in the event of a SR 520 bridge failure.
- Develop "lessons-learned" that could be incorporated into future plans and activities addressing longer-term consequences and challenges associated with the resilience of the regional economy and moving people and freight.
- Obtain information from participants that could be used to develop a transportation management plan and a communications plan to be implemented in the event of a SR 520 bridge failure.

Figure 1: Focus area and coordinating jurisdictions.

2.2 Action strategy workshop

Tabletop exercise participants met for a follow-up action strategy workshop. The goal of the workshop was to discuss and prioritize transportation management activities on the basis of findings and recommendations from the tabletop exercise. Specific action strategies were developed in the areas of communications, emergency management, economic issues, freight issues, and mobility.

3 Transportation management plan

3.1 Bridge failure scenario

Of the failure scenarios considered during preliminary catastrophic failure planning, the final transportation management plan assumed only a windstorm-caused loss of the SR 520 bridge. In this scenario, it was assumed that the approach structures would remain operational.

An earthquake scenario could result in significantly more infrastructure damage than just the SR 520 bridge and its approaches, possibly affecting other regional structures. Because of the broad-scale damage that could result from such a disaster, evaluation of an earthquake scenario was determined to be beyond the scope of the transportation management plan. However, most of the conclusions and recommendations outlined in the plan—while focused on the loss of the SR 520 floating bridge structure only—are intended to be useful in a variety of bridge failure and other emergency scenarios.

3.2 WSDOT's priorities for managing regional highway facilities in the event of a SR 520 bridge failure

The strategies described in the transportation management plan were developed to move people and goods as safely and efficiently as possible in the event of a SR 520 bridge failure. Given the already congested highway system, a transit and transportation demand management response will be vital to keeping traffic moving on the regional highway system. This approach allows movement of the most people in the fewest number of vehicles. Therefore, the roadway improvements described here were identified to prioritize efficient transit and high occupancy vehicle (HOV) travel, and to maintain reliability and travel time as much as possible without compromising safety.

3.3 Evaluated facilities

The SR 520 project team reviewed the results from the SR 520 travel demand model used during preliminary catastrophic failure planning which estimated potential changes in traffic patterns with the loss of the SR 520 bridge. Based on these results and additional analysis, the project team focused its analysis on state routes that would be expected to carry the majority of the displaced bridge traffic (Figures 2 and 3). A broader area was evaluated for the transit component of the transportation management plan, which included a review and evaluation of service and infrastructure improvements beyond WSDOT facilities. Review elements included locations for more bus stops, park-and-ride facilities and transit centers.

3.4 Key outreach participants

The SR 520 project team met with transportation managers and public information officers from local jurisdictions in a series of meetings. These meetings were important because they allowed jurisdictional staff to share their respective concerns and to collaborate on the development of initial transportation management and communications strategies. The SR 520 project team worked with the local Jurisdictions, transit agencies, and WSDOT Public Transportation and Freight Systems Divisions throughout the transportation management plan development process.

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Figure 2: Current cross-lake Washington traffic patterns [4].

3.5 Key transportation management strategies

In the event of a SR 520 bridge failure, WSDOT will act quickly to ensure the maximum safety and efficiency of the regional highway system. Detailed response strategies and transportation demand management tactics listed in the transportation management plan describe how WSDOT will approach this.

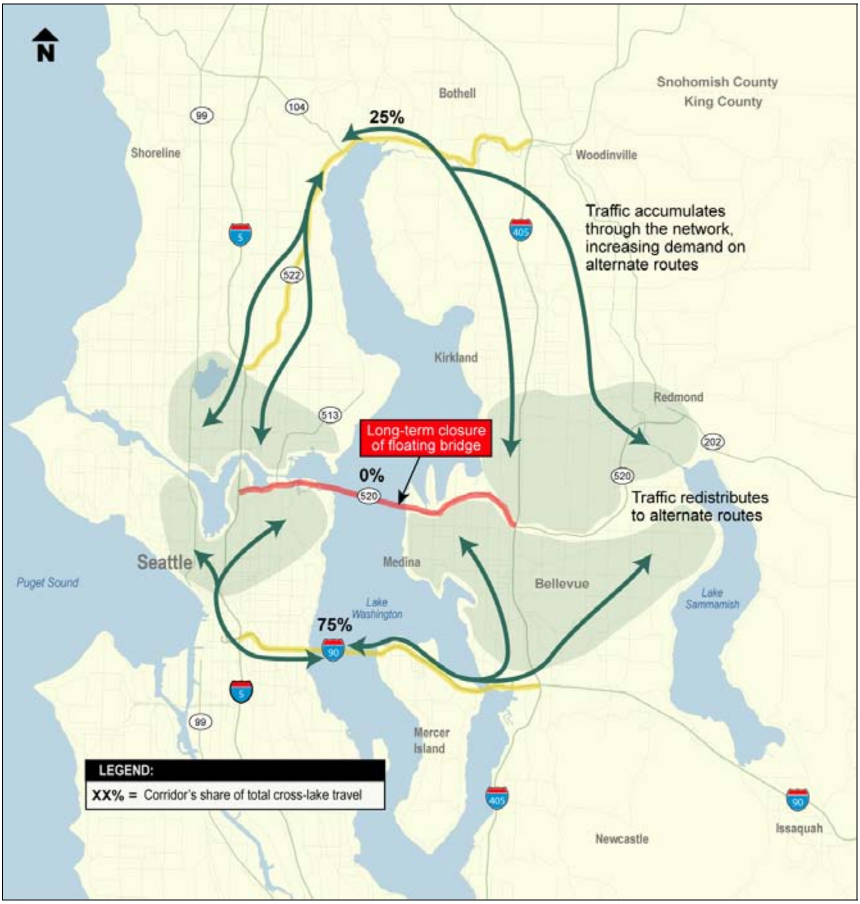

Figure 3: Projected cross-lake Washington traffic patterns following a SR 520 bridge failure [4].

3.5.1 Strategies for the central Puget Sound region's major corridors

The transportation management plan further details a series of suggested transportation management packages that could be implemented as first steps to keep the region moving after a SR 520 bridge failure. These packages are intended to be used as an initial starting point for traffic mitigation. They can be implemented within one month of a catastrophic bridge failure; other packages described in the transportation management plan are designed for implementation within a longer timeframe.

Some of the packages are temporary in nature and are intended to be in service under emergency conditions while the SR 520 structures are being replaced. Design standards, such as speed and lane width, would be evaluated when implementing the temporary strategies to determine whether design deviations should be considered. Some of the packages build upon plans that are already in design or are programmed for construction. In the event of a SR 520 bridge failure, WSDOT would determine which of these projects would be accelerated or delayed based on the changed traffic conditions. Recommended strategies or packages are to be quickly implemented on one of the region's key transportation corridors after a catastrophic bridge failure: SR 520, I-90, I-5, SR 522, SR 523, and I-405.

3.5.2 Transit agencies' role in addressing mobility

In the event of a SR 520 bridge failure, transit service would play a key role in maintaining mobility throughout the region, particularly across Lake Washington. There are three major considerations regarding the role of transit agencies in addressing mobility following a SR 520 bridge failure:

- Transit will need fast and reliable paths to be an effective transportation mode, requiring commitment to transit priority.
- Public awareness and rider incentives will be needed to ensure that people take maximum advantage of available transit service.
- Availability of equipment, personnel and particularly funding will constrain how quickly new transit service can be added and the total amount of additional transit service that will be possible.

Modifications to transit service following a SR 520 bridge failure includes discussion of how service would likely be modified to provide connections between major centers on the west and east sides of Lake Washington. Rider incentives Strategies should also include increasing the effectiveness.

3.5.3 Managing transportation demand

Transportation demand management (TDM) uses existing infrastructure as efficiently as possible and implements programs to reduce demand for transportation facilities. In the event of a SR 520 bridge failure, it will be critical to make the best use of the available infrastructure by increasing the use of alternative travel modes and work arrangements.

TDM strategies such as expanded employer-sponsored commuter benefits programs and new demonstration programs are also part of the transportation management plan.

3.5.4 Freight considerations

For freight traffic, returning traffic operations to as close to pre-failure conditions as soon as possible will be critical. This is consistent with the transportation management plan goal of maintaining reliability and travel times. Towards this end, the planned regional projects and recommended traffic management strategies focus on improving overall traffic operations on regional freeway systems in the event of a SR 520 bridge failure. While many of the recommended improvements would benefit freight movement, the transportation management plan does not provide specific strategies for improving freight movement in the event of a bridge failure. Such strategies would require regional policy deliberations and additional coordination with local agencies that were not part of the scope of this planning effort.

3.6 Transportation management next steps

The transportation management plan provides a starting point in identifying a range of possible strategies to manage the regional transportation system in the event of a SR 520 bridge failure. The plan suggests a process for implementing appropriate strategies in a timely manner following a bridge failure. It also suggests early actions and strategies that could be advanced to enhance regional preparedness.

4 Communications plan

To prepare for a possible SR 520 bridge failure, the WSDOT, in collaboration with regional jurisdictions and agencies, has developed a communications plan. In the event of a bridge failure, the plan will support emergency response, bridge recovery and bridge restoration efforts through development, coordination and dissemination of emergency public information.

The plan will serve as a guide for WSDOT communicators to use if a catastrophic failure were to occur. The plan builds on current communications strategies that have been implemented when unplanned, short-term closures have occurred in the past (e.g., during several recent winter windstorms) and identifies specific tools and strategies to utilize if SR 520 is closed for a longer period of time.

4.1 Purpose

Emphasizing public safety is WSDOT’s first priority in the event of a SR 520 bridge failure. Also important is to ensure public confidence in WSDOT as a credible and accountable organization. The communications plan should provide effective guidelines, strategies and tools for WSDOT communications staff in the event of a SR 520 bridge failure. The plan outlines suggested guidelines, strategies and tools for jurisdictions and agencies to effectively disseminate critical, core information to their constituencies. It also establishes clear and effective communication lines between WSDOT and local, regional, state and, if needed, federal personnel while providing a communications framework that ensures consistent messaging across agencies.

4.2 Assumptions

4.2.1 Incident command system and emergency operations centers

In the event of a SR 520 bridge failure, it is assumed that the incident command system, under the National Incident Management System, would be utilized. It is also assumed that the emergency operations center at WSDOT’s Northwest Region Dayton office in Shoreline would be activated. It is also likely that other state and regional emergency operations centers would activate, depending on the event severity and its regional effects.

4.2.2 Bridge failure scenario

The communications plan does not specify a particular SR 520 bridge failure scenario. It assumes that the strategies and tools identified may be universally applied in any medium- to long-term closure of the SR 520 corridor, including the Evergreen Point floating bridge, the Portage Bay viaduct, and the surrounding roadways or approaches. In either an earthquake or severe windstorm event, it is assumed that a failure of SR 520 would be part of a larger regional situation. Viewing simulated visualizations of how the SR 520 bridge could fail in either an earthquake [5] or a windstorm [6] assisted the public to understand the vulnerabilities of the floating bridge, and gave a sense of realism to the failure scenario.

4.2.3 Timeframe

The communications plan outlines activities and strategies for different phases of a potential catastrophic failure: pre-storm, the response phase, and the recovery and restoration phase. The official transition between the response and the restoration occurs when the incident command post is dismantled.

4.3 Key players and resources

WSDOT is the lead agency in communicating and disseminating information about the SR 520 bridge. WSDOT will work closely with King County and local municipalities and assist with other regional transportation agencies. WSDOT will rely on a variety of communications outlets and resources to help communicate messages during a SR 520 closure. These resources include: the WSDOT Web site; 5-1-1 CARS hotline system; television, radio and print media; regional Public Information Network (www.rpin.org); Northwest Warning, Alert, Response Network (NW-WARN www.nwwarn.org); other regional, state and local emergency operations centers; and public information officers and communications staff from coordinating jurisdictions and agencies.

4.4 Communication strategies

The following key strategies will be implemented during a SR 520 closure: no surprises, coordinate messaging, manage expectations, lead with the Web, utilize the 5-1-1 CARS hotline system, establish innovative means of communication when power and telephone lines are out, choose spokespeople strategically, and show and tell the response and recovery story.

4.5 Objectives

WSDOT’s overall objectives for communications during a catastrophic event will be to provide information to travelers, freight, neighbors and others who are affected so they can make informed decisions; keep public trust; and to minimize on-scene disruptions during the immediate response and recovery phases to allow emergency responders to do their work effectively.

4.6 Key audiences

In the immediate response phase, and when the SR 520 bridge is closed during the recovery phase, there are many key audiences to be considered. Due to the regional significance of SR 520, the critical audiences are broad and wide-reaching. They include: emergency service providers; local, regional, state and federal transportation decision-makers; media; transit agencies; utilities; local jurisdictions, neighbors and community organizations; drivers and commuters; freight carriers; school districts and higher education institutions; businesses and employers; traditionally under-represented and special needs groups; tribal nations; and regulatory agencies.

5 Conclusion

WSDOT already has established SR 520 emergency management procedures with current SR 520 traffic control plans. Also there is a WSDOT bridge inspection manual which documents the procedures for closing the SR 520 bridge during emergencies and non-emergencies [7]. WSDOT Northwest Region prepared a guide for SR 520 bridge closures that identifies traffic control plans and provides suggestions for operating highway advisory radio and variable message signs during such closures [8]. The catastrophic failure plan goes a step further. It represents a toolbox of strategies that can be implemented to keep central Puget Sound drivers and commerce moving during a long-term recovery from a SR 520 bridge failure.

The catastrophic failure plan, composed of a transportation management plan and a communications plan, outlines options to ensure safety, efficiency and effective public relations in the event of a SR 520 bridge failure. The transportation management plan describes practical traffic mitigation solutions to keep Puget Sound moving in the event of a catastrophic SR 520 bridge failure.

Keeping drivers and transit riders informed about current roadway conditions and ongoing traffic restoration efforts will be essential to the success of this plan. To achieve this, WSDOT has also developed a communications plan. Communication will support emergency response, bridge recovery and bridge restoration efforts through the development, coordination and dissemination of emergency public information.

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Seismic retrofitting on structures in urban areas

A. K. Desai
Applied Mechanics Department, S V National Institute of Technology, Surat, India

Abstract

After the Bhuj earthquake event in 2001, earthquakes and seismic hazards are increasing as the Indian continent (Tectonic Plate) moves slowly towards the North-East Himalayan Mountain side. Now, because of the collision of two tectonic plates and due to a folding of the plate, the top crust is subjected to tension cracking. This is the main cause of earthquakes in the Asian region. The frequency of earthquake shocks from different epicenters is increasing as compared to previous shocks.

The Indian government modified its seismic design code from I.S.: 1893–1984 to I.S.: 1893–2002, for seismic safety in its newly designed buildings. However, problems do arise for old structures, as quite a large part of the Indian population resides in urban areas and some even in poorly constructed RCC buildings, with a seismic risk zone from Zone–III to Zone–IV (most dangerous). The only option remaining for local authorities for reduction of earthquake hazards and for increasing the safety of the urban population is for "Seismic Retrofitting" of old structures. Three aspects are most important for prioritization of structures that need retrofitting

1. Structures of national importance, lifeline and critical facilities.
2. Multi-storied residential and commercial complex.
3. Only ground floor/ low rise residential building.

Again, structural auditing for three aspects are required for priority of retrofitting - structures near to collapse, but can be refortified and require steel probe supporting; main structural components like beams and columns that require immediate retrofitting at some places; structures can be made safe following this old design code, but retrofitting is required from a new design code for higher level earthquakes. After mixing the above two auditing criteria, the availability of a

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110151

"Retrofitting fund" and cost effective "Retrofitting method" must be thought of, for urban life safety.

Keywords: effect of earthquake, retrofitting method, old and new building audit, seismic hazard, safety.

1 Introduction

Earthquakes can pose one of the greatest challenges to the designer of buildings and other civil engineering structures. The potential for violent ground motions lasting not more than a few minutes to cause great destruction has been amply demonstrated by recent events.

As narrated by Shah *et al.* [1], lessons learnt from the Bhuj earthquake (26/01/2001), in combination with research efforts and new technologies, lead to changes in the I.S. Code (1893–2001) of practice, for designing more reliable structures. But what to do with those existing structures which were constructed before the imposing of advance seismic code or structures that were built with inherent conceptual detailing or construction error.

Experience from past earthquakes and results of structural analysis indicate that a large proportion of the existing reinforced concrete buildings in Gujarat (or any) is vulnerable to damage or even collapse during a strong earthquake. These structures neither possess sufficient strength nor ductility to perform satisfactorily during future earthquakes. Consequently, there is a need to redesign all structures constructed in the past, and not just which have been damaged during earthquakes. However, the cost of redesigning all damaged structures will be too high and also "old" structures which provide essential service such as hospitals, schools and telecommunication structure should be protected, not only to avoid collapse, but also to ensure that important social function are maintained even after a strong seismic shock. So retrofitting of certain structures is essential.

1.1 Characteristics of earthquake effects on structures

Some of the key factors which differentiate the effects of earthquakes' strong motion from other types of loading are listed below.

- i Earthquake loading arises from ground accelerations causing inertial forces within a structure. These are dynamic effects i.e. the dynamic properties of the structure determine the severity of the response.
- ii Earthquake loading is cyclic in nature, and the potentially degrading effect of such loading on structures and foundation soils must be taken into consideration
- iii There is great uncertainty in the amplitude, duration and frequency content of the motions that may be expected at a particular site, moreover, the response of structures to such complex motions, even if these motions were known with certainty, is often difficult to predict with confidence.
- iv Earthquake motions with a long return period (very low annual probability) are proportionately large compared with short-return period motions.

There are approximately 120 million buildings in seismic Zones III, IV and V. Most of these buildings are not earthquake-resistant and are potentially vulnerable to collapse in the event of a high intensity earthquake. It is not practically feasible or financially viable to retrofit all the existing buildings. The guidelines given by the National Disaster Management Authority (Government of India) are helpful in selecting the buildings which need seismic strengthening. These guidelines recommend the structural safety audit and retrofitting of select critical lifeline structures and high priority buildings.

1.2 Prioritization of structures

The initial focus for structural safety audit and retrofitting will be on government and public buildings. For private buildings necessary capacity for carrying out assessments is to be developed through suitable capacity development efforts among the professionals in the private sector.

Here is an illustrative priority list for Structural Safety Audit, Seismic 1.3 Strengthening of structures.

Buildings of national importance like Rashtrapati Bhavan, Parliament House, the Supreme Court of India, Raj Bhavans, Legislatures, High Courts, Central and State Secretariats, historical monuments, museums, heritage buildings, strategic assets and vital installations such as power plants.

Lifeline buildings, structures and critical facilities like schools, colleges and academic institutions; hospitals and health facilities, tertiary care centers and all hospitals designated as *major hospitals.*

i Public utility structures like reservoirs and dams; bridges and flyovers; ports and harbors; airports, railway stations and bus station complexes.

ii Important buildings that ensure governance and business continuity like offices of the district collector and superintendent of police in districts; buildings of financial institutions like the Reserve Bank of India and the stock exchanges.

iii Multi-storied buildings with five or more floors in residential apartments, office and commercial complexes.

However the responsibility to identify and prioritize these structures will rest with respective state governments.

1.3 Structural safety audit of critical lifeline structures

The seismic risk profile can be quantified only after the vulnerability of building inventory in a geographic area is compiled. Assessment techniques can be used to determine the vulnerability of the buildings, in order of priority. Two levels of seismic vulnerability assessment can be carried out for buildings, namely Rapid Visual Screening (RVS) and Detailed Vulnerability Assessment (DVA). The former is a quick visual estimation but cannot give detailed technical information of structures to determine whether the structure is considered to be vulnerable or not. Once the RVS identifies a structure to be vulnerable, then that structure is subjected to a detailed assessment for a quantitative evaluation of its vulnerability. For structures other than buildings, DVAs are normally carried out. A DVA consists of evaluating the structural systems that resist the earthquake loads, as well as assessing non-structural elements like the contents, finishes and elements that do not resist any earthquake load of the structure.

RVS procedures need to be developed for all types of building systems in India.

1.4 Seismic strengthening and retrofitting

The seismic strengthening and retrofitting of some fragile lifeline structures is undertaken through a pilot project being implement by Government of India. The prioritization of the cities is based on the

- degree of seismic hazard,
- population size,
- level of vulnerability of the building/structure,
- importance of the structure, and
- the speed with which the states can undertake these initiatives.

Accomplishing seismic retrofitting of the existing built environment requires a systematic and sustained effort, by carrying out several activities in each of the towns and cities. These activities are:

- Developing an inventory of the existing built environment.
- Assessing the vulnerability of these constructions.
- Prioritizing structures found vulnerable.
- Developing seismic retrofitting measures.
- Undertaking construction work to strengthen vulnerable structures.

2 Cracks and earthquake affected structures

As per I.S. 13935:1993 [2] for repair and seismic strengthening of building guidelines it is classified as per width of cracks

i Minor cracks - These cracks are very fine cracks. Generally shown in concrete structure, only a crack width near a 0.5 mm is called minor cracks. These are also called a hair cracks.

ii Medium cracks - The crack width near 0.5 mm to 5mm called as a medium cracks. Generally, observed in masonry and concrete.

iii Major cracks - The crack width wider than about 5mm is called major cracks. Generally it is shown in masonry and concrete.

As presented by Jain Sudhir and Murty [3] crack patterns are very important in seismic engineering, because by using cracks patterns we can judge the effect of earthquakes on a building. For the repair of minor and medium cracks (0.50mm to 5mm), the technique to restore the original tensile strength of the cracked element is by pressure injection of epoxy, briefly explain in retrofitting technique topic. For cracks wider than about 5mm or for regions in which the concrete or masonry has crushed, a treatment other than injection is indicated is also briefly explained in the retrofitting technique topic. Cracks can be further classified as, flexure cracks, shear cracks, sliding, or combined. As narrated by Mukherjee Abhijit and Joshi Mangesh [4] fibre composites are effective for repair of minor and medium crack in R.C.C. structures.

3 Post earthquake damage evaluations

3.1 Emergency earthquake damage evaluation

Immediately after a damaging earthquake, an initial evaluation of each structure will be made by the official inspection team to determine quickly the general level of damage to the structure and if the structure is safe for continued occupancy.

Based on this initial evaluation each examined structure may be in one of the main categories labeled as follows:

i Green - This category is for buildings whose original seismic capacity has not been decreased and which do not appear to pose any danger to human life. The buildings are immediately usable and the entry unlimited. These building may have sustained slight damage requiring repair.

ii Yellow - Buildings in this category have decreased seismic capacity. Limited entry at owner's risk is permitted but not usage on a continuous basis. The need for supporting and protection of both the building and its surrounding should be considered.

iii Red - Buildings in this category are unsafe as subject to sudden collapse. Entry is prohibited and building surroundings should be protected. Decision for demolition will be made on the basis of a more thorough inspection after investigating technical possibilities for repair and for strengthening and their economic justification.

3.2 Preliminary investigation

The main purpose of the preliminary investigation of the state of the structure is to determine in detail the nature and degree of damage and to design and install emergency measures for temporary support to avert the risk of casualties and injuries, as well as to minimize the possible material losses in case of increased damage to the structure. The probability of repeated seismic activities during the days after the first shock is quite enough. Moreover, increased damage resulting from earthquake effects is often due to the dead and live loads where the continuity of the stress path of the forces to the foundations is partially or fully interrupted. The preliminary investigation will also be utilized in determining repair and /or strengthening measure.

4 Case study of a residential building structure

The building is located in South Gujarat region. It is designed for a ground level plus six floors, all under construction. Presently, ground plus three floors of the reinforced concrete building are constructed. The building was severly damaged during the 26th January 2001 Bhuj earthquake (magnitude 7.2 Richter scale, duration 108 seconds). The building was approximately 400 kilometres away from the epicentre, but still large cracking and damage was observed. The building structure is analytically solved with different types of retrofitting methods. Figure 1 shows the typical plan of the building and all structural details of the building are enclosed in the envelope. As seen in plan, there are four flats on each floor and separated by stair portion. The expansion joint is provided between flat portion and stair portion.

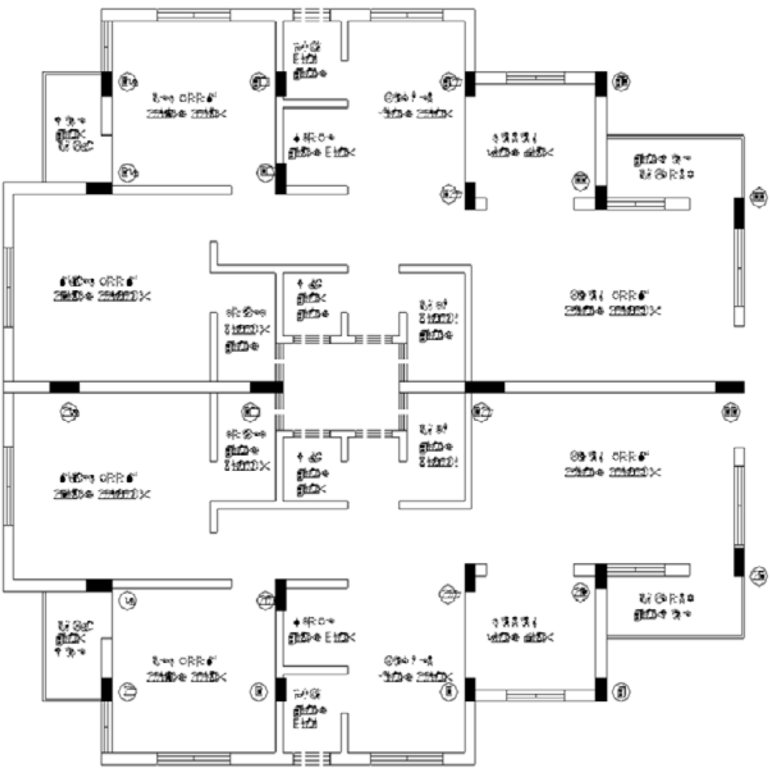

Figure 1: Plan of the building.

Three techniques are used for analysis to achieve a comprehensive strengthening of the structure as a whole. These techniques are

i Retrofitting by Reinforced concrete Jacketing.
ii Retrofitting by Adding Diagonal Bracings.
iii Retrofitting by new Shear walls.

The other techniques are not suitable for the local corporation by laws, organizer commercial purposes and also some of them are not feasible. The STAAD -III is use for analysis Purpose. STAAD-III is comprehensive and flexible general purpose structural software that address to all aspects of structural engineering. The codes used for analysis and design are IS 456:2000 and IS 1893:1984. The compressive strength of old structure was measured employing Non Destructive Testing using Rebound Hammer method.

Figure 2: Photo of the building being constructed.

Different loading combinations for analysis and design are considered which basically comprises of dead loads, live loads and earthquake loads.

Steps for structural analysis of the building with reinforced concrete jacketing:

i Analyze the building for Dead Load and Live load with actual site member properties.

ii Analyze the building for Dead load, Live load and Lateral load in four directions with actual site member properties.

iii Analyze the building after applying Jacket to all columns (vertical member) at ground floor with Dead load, Live load and Lateral load.

iv Analyze the building after applying Jacket to all columns (vertical member) at Ground Floor and only corner columns at first floor with dead load, Live load and Lateral load. Analyze the building after applying Jacket to all columns (vertical member) at Ground Floor and only periphery columns at first floor with Dead load, Live load and Lateral load.

Figure 3: Jacketing of columns.

- v Analyze the building after applying Jacket to all columns (vertical member) at First Floor with Dead load, Live load and Lateral load.
- vi Analyze the building after applying Jacket to the columns (vertical member) which are biaxial fail at Second floor with Dead load, Live load and Lateral load.
- vii Analyze the building after applying Jacket to all columns (vertical member) Second floor with Dead load, Live load and Lateral load.
- viii Analyze the building after applying Jacket to all columns (vertical member) up to Second floor and only corner columns at Third floor with Dead load, Live load and Lateral load.
- ix Analyze the building after applying Jacket to all columns (vertical member) up to Second floor and only periphery columns at Third floor with Dead load, Live load and Lateral load.
- x Analyze the building after applying Jacket to all columns (vertical member) up to Third floor with Dead load, Live load and Lateral load.

xi Analyze the building after applying Jacket to all columns (vertical member) up to Third floor and only periphery columns at Fourth floor with Dead load, Live load and Lateral load.

xii Analyze the building after applying Jacket to all columns (vertical member) up to First floor and only the columns which are biaxial fail up to Fourth floor with Dead load, Live load and Lateral load

4.1 Application of reinforced concrete jacketing to the building structure

Reinforced concrete jacketing according the available space conditions around the columns can be performed by adding jacketing to one, two, three or four sides of concrete column sections (Fig. 3). It is strongly recommended that columns be jacketed on all four sides for best performance in future earthquakes. In order to achieve the best bond between the new and the existing concrete, four sided jacketing is also most desirable. In case one, two, or three sided jacketing is all that is possible, the concrete cover in the jacketed parts of the existing column must be chipped away so new ties can be welded to existing ties.

Figure 4: New pad foundations.

4.2 Addition of diagonal braces in the building

Diagonal bracing is used when there is a requirement of a moderate strength increase, while a great ductility and stiffness enhancement of the whole structure is desirable. Main advantages of the technique are speed of application, the uninterrupted natural lighting of the space. When brick-masonry walls already exist in the selected frame bays, the method can be applied by adding the bracing system externally on the frame or to demolish the existing masonry wall then provide bracing and then again fill with masonry wall.

4.3 Addition of shear walls in the building

Cast-in-situ shear walls are constructed in properly selected frame bays of the structural system between the existing columns and beams of the frame. The walls are generally cast-in-situ but may be installed with shot-crete. Precast, prefabricated concrete elements can be used. The favorable position of new added element (Shear wall) should be in such a way that the centre of mass of the building and centre of stiffness of the building coincide or the distance between centre of mass of the building and centre of stiffness of the building be less. Even though bracing is provided up to the fourth floor, the columns which are perpendicular to the x-axis fail in biaxial bending. So, it is advisable to add a jacketing system (i.e. combination of the system). Hence, the building can resist future earthquake loads.

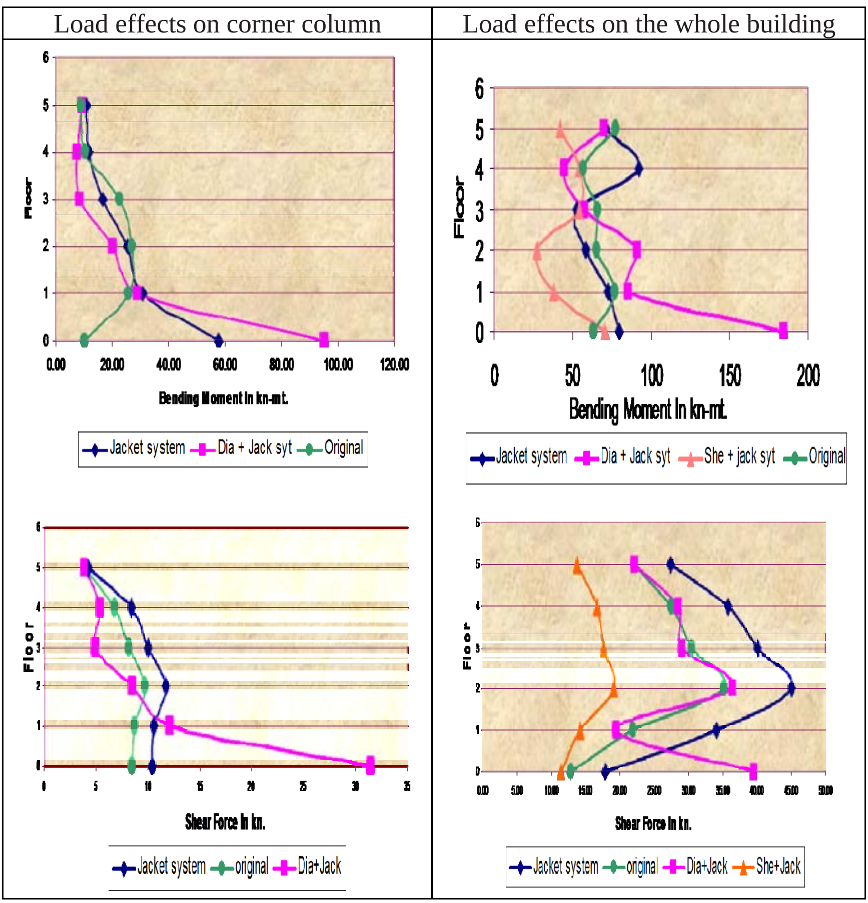

Figure 5: Results (load effects) showing comparison between the retrofitting methods used.

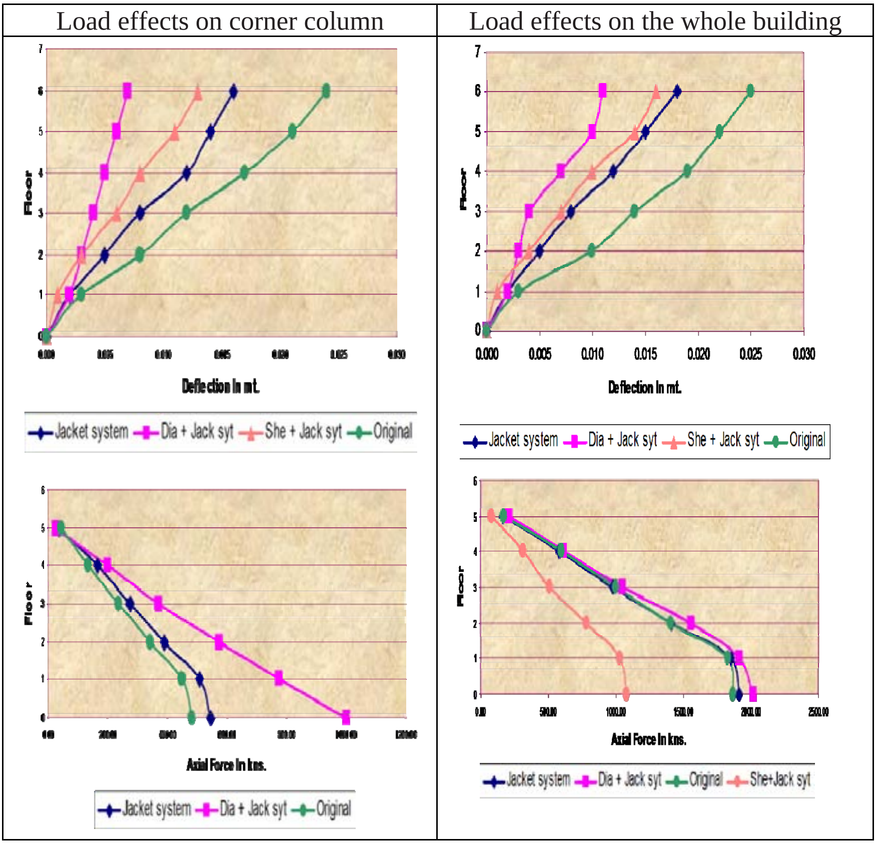

Figure 5: Continued.

5 Results and discussion

The results obtained from the output of Staad-III various graphs are plotted. The graphs are plotted floor level versus Bending Moment, Shear Force, Deflection, and Axial Forces of the building. On the X-axis Bending Moment (kN-mt), Shear Force (kN), Deflection (mt), and Axial Force (kN) and on the Y-axis different floor levels of the building are plotted.

i The choice of a suitable retrofitting methods and appropriate strengthening technique is not an easy matter, ever since intervention is a unique case. This has a parallel saying in medicine, “There are no diseases but patients”. Here, this can be restated as, “There are no structural deficiencies, but deficient structure”.

ii Undoubtedly, for the above case study, the retrofitting methods aimed at achieving comprehensive strengthening of the structure as a whole gives better solution.

iii As a thumb rule, if the cost of strengthening and retrofitting is less than about 50% of the reconstruction cost, the retrofitting is adapted. So, retrofitting methods for this building is recommended as it worked out so.

iv Addition of new element (shear wall) is a better solution for a particular building due to the following reason;

a. Bending moment is less in Shear wall plus Jacketing method.
b. Shear force is also less in Shear wall plus Jacketing system.
c. In deflection, the Shear wall plus Jacketing system is second then the diagonal bracing plus jacketing system.
d. As per cost analysis, the cost of Shear wall plus Jacketing methods is less.
e. The form work for the shear wall methods is also easy.

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Section 3
Risk mitigation

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Promoting the hybrid socio-technical approach for effective disaster risk reduction in developing countries

D. Karnawati[1], T. F. Fathani[2], W. Wilopo[1], A. Setianto[1] & B. Andayani[3]
[1]*Department of Geological Engineering, Gadjah Mada University, Indonesia*
[2]*Department of Civil and Environmental Engineering, Gadjah Mada University, Indonesia*
[3]*Faculty of Psychology, Gadjah Mada University, Indonesia*

Abstract

This paper highlights the importance of integrating social and technical approaches (which is the so-called "hybrid socio-technical approach") as one innovative and strategic program with respect to disaster risk reduction. Such a program is mainly based on multi-disciplinary action research to support the community empowerment program through public education. The technical approach was mainly conducted for geological and geotechnical investigation to analyze and predict susceptibility levels of the disaster prone area, as well as to develop an appropriate technology for hazard mapping and disaster early warning. Meanwhile, the social approach was necessary for analyzing and mapping the psycho-social conditions of the disaster prone area, and accordingly an appropriate strategy and program to implement the early warning technology can be formulated. Moreover, it is also important to establish a "community task force" as the driving power for landslide disaster risk reduction which can sustain the program at the village level.
Keywords: hybrid socio-technical system, indigenous technology, life and environmental protection, community empowerment.

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110161

1 Introduction

Indonesia is situated in such a dynamic geological region that it is frequently struck by various types of geological disasters such as earthquakes, tsunami, volcanic eruption, landslides and debris flood. Unfortunately, this region is occupied by a high density population, and those disasters continuously cause substantial death tolls, casualties, and socio-economical losses. According to [1], Indonesia has been struck by 6,632 events of natural disasters (mainly geological disasters), within the period of 1997 to 2009, with a total death toll of 151,277 people. Therefore, it is very important to urgently develop appropriate disaster management for life protection and environmental sustainability through the improvement of society resilience in such a disaster prone area.

2 Problems in disaster risk reduction

The development of a hazard map and the application of an appropriate technology for an early warning system are considered as parts of crucial efforts to reduce the risk of disasters. Unfortunately, the effectiveness in providing a hazard map and an early warning of disasters cannot be guaranteed due to less consideration on the social (including the cultural) conditions at the disaster area. Obviously, the need to integrate the social consideration into technical measures for disaster risk reduction should be addressed in order to assure the effectiveness in any implementation of such a hazard map and early warning system for disaster risk reduction [2].

3 Concept of the hybrid socio-technical system

To ensure the effectiveness in the implementation of any technology for disaster risk reduction, a combined (hybrid) system which considers both social and technical aspects needs to be developed. However, it is recommended to develop the existing indigenous or local technology through a community participation process. To allow such effective participation, a simplicity of the applied system and technology, and also the utilization of local material by local knowledge (local experts and local operators) through a local participation program must be considered. That is why it is important that the hybrid system should be performed with a low cost and simple technology or method which can be easily understood, operated and maintained by the local community, such as suggested by [3]. All of these concepts can be done only if the local community has been empowered. Therefore, the process of technological development can be carried out during or as a part of the process of community empowerment.

4 Pilot implementation of the hybrid socio-technical system

A hybrid socio-technical system has been implemented in one pilot area in Central Java, especially in Karanganyar Regency. This Regency is situated at the

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western slope of Lawu Volcano, in which 30% of the region is at high risk of landslides due to the high susceptibility condition (indicated by red [dark] color in the map of Figure 1), which is controlled by the geology and climate conditions, and also because of the high vulnerability of the socio-economical conditions in the landslide prone area [4].

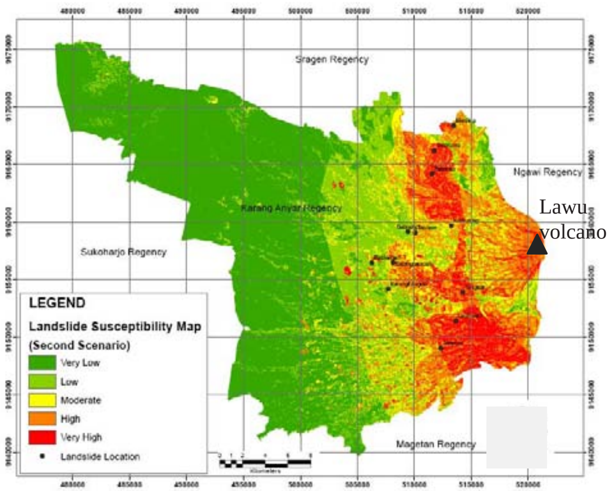

Figure 1: Landslide susceptibility map of Karanganyar Regency, Central Java, Indonesia, developed in regional scale of 1 : 100,000 [4].

Admittedly, it is impossible to change the natural (i.e. geology and climate) conditions in order to reduce the landslide susceptibility, but it will be more feasible to manage the social conditions for reducing socio-economical vulnerability in the landslide prone area. Therefore, landslide disaster risk reduction in the pilot study area was conducted by adaptive management as suggested by [5] and [6], which emphasized the improvement of community resilience, through the development of a hybrid socio- technical system.

4.1 Social system development

Development of the social component in the hybrid system was initiated by public education with various target groups such as women (as the key person in the family), teachers, children as well as the young and senior leaders. The local government of Karanganyar Regency also continuously and actively supported this social development program.

To ensure the effectiveness of public education and the development of the hybrid system, social survey was carried out. The base level of community understanding on landslide phenomena and its prevention method, together with the community perception and expectation on the proposed developed technology were also identified from the social survey. In addition, this survey found that most of the community members had been quite aware of the potential occurrence of landslides in the rainy season, because the landslide disasters have frequently struck their region, especially under the extreme weather conditions. Nevertheless, most of the community members preferred to remain living in their vulnerable region, instead of being relocated to the other safer areas. Obviously, the fertility of soil, the abundance of water resources, the beauty of mountainous panorama and the strong psychological engagement with their homeland or home-heritage, have strongly prevented their willingness to leave their dangerous homeland. Unfortunately, they do not have enough knowledge, skill and capacity to identify the zone (which part) in their village which is susceptible to landslides, the symptoms that landslide will occur, and also to decide about "what should" and "what should not do" for preventing the landslide. Thus, the capacity of the community to protect their life and environment needs to be further improved, with respect to the improvement of their resilient. Therefore, a simple hybrid socio-technical system for community-based landslide early warning was urgently required.

Again, the hybrid system was developed by the combination of social and technical systems. Initiated by public education and community participation, the social system was developed through the establishment of a community task-force for disaster risk reduction at the village level (Figure 2), under coordination with the Agency for Disaster Management at the Regency level. This network is also linked to the local hospital (health center), the local army and police, and also the Search and Rescue Team (SAR team) at the local Regency.

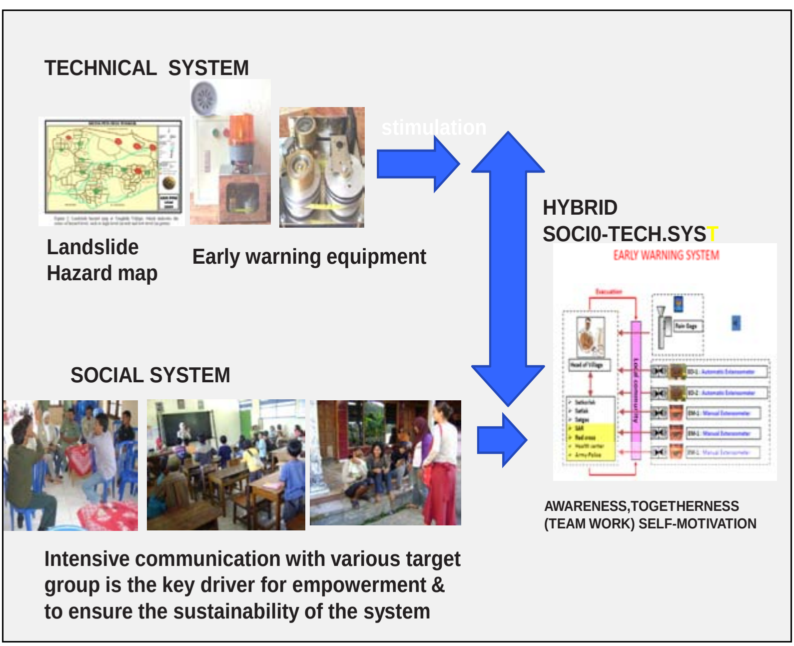

Figure 2: The concept and key components of a hybrid socio-technical system for landslide mitigation and an early warning system.

4.2 Technical system development

Technical system development consists of development of a community landslide hazard map and an early warning system.

4.2.1 Landslide hazard map

The landslide hazard map was developed by applying the simple community hazard mapping method, suggested by [7]. The map was not prepared with the standard topographical map (standard technical map) which is usually conducted for hazard mapping. Learning that most of the technical map was not easy to be understood by the local community, thus in this community the hazard map of the village layout map, which was prepared by the local community, was applied. Such a map was presented without any contours, but mainly showing the layout of roads, rivers, houses and land farming areas which were very easy to be identified by the local community. Identification of the zone of high susceptible (red zone) and low susceptible or safe zone (green) for landslides was carried out by public participation with support by the adviser. This adviser should have enough knowledge for landslide hazard mapping. Figure 3 shows the landslide hazard map which was developed by the local community in Tengklik Village, Tawangmangu District, Karanganyar Regency, Central Java.

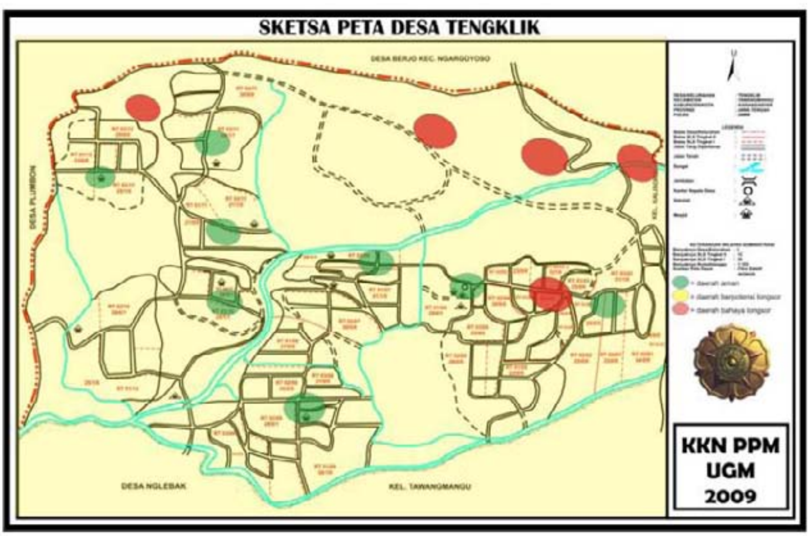

Figure 3: Community-based landslide hazard map of Tengklik village, Karanganyar Regency, central Java [7].

Through this approach and the simple method of landslide hazard mapping, the map will be easier to be understood and implemented by the local community. This map is also very important to decide how and where the early warning system should be developed. Therefore, the understanding and simplicity of the approach and method of mapping is the most critical part to guarantee the effectiveness of the disaster risk reduction program.

4.2.2 Early warning system

The technical system for landslide early warning was supported by several sets of equipment listed below:

1. Rain gauge (1 set) to monitor the rain precipitation in millimetres per hour.
2. Manual extensometers (5 sets) with the siren alarm generated by a dry battery, to monitor the landslide movement on the slope in cm.
3. Solar panel (2 sets) to support the recharging of the dry battery.

The rain gauge was installed in the open space to record the rain precipitation which potentially induced land-sliding. Such a rain gauge was connected to an alarm and the alarm was set to be ON with a loud sound, when the accumulative rain infiltration had exceeded 100 mm. This critical number of rain infiltration was set based on the previous research conducted by [8] and [9]. The alarm due to rain gauge warning was deliberately designed to raise the community alert, to immediately prepare for evacuation before the landslide event.

In many cases it is apparent that a crack at the ground surface always occurs prior to the landslide disaster event. Thus, the crack-extension can be used as the indicator of initial slope movement just before a landslide occurs. That is why monitoring on the crack extension was implemented to provide the warning system prior to the event of landslide disaster. Accordingly, the extensometer was designed in the pilot area to monitor the extension of the crack, by allowing the wire of such an extensometer to be pulled automatically across the crack, in response to the extension of crack induced by the slope movement. If the wire of the extensometer was pulled up to 4 cm length (this length was defined based on the previous empirical analysis at a similar susceptible landslide area), the connected alarm will give such a loud sound as the early warning to the community, so the community have to start to move away from the respective slope.

5 Evaluation

The establishment of a community task force for landslide disaster risk reduction at each village level is the most critical and important factor to ensure the effectiveness and sustainability of landslide mitigation. This task force had an important role as the driving agent in the empowerment and mitigation program. Since the hybrid socio-technical system which is supported by the community task force was applied in the pilot area in Ledoksari Village in 2008 and Tengklik Village in 2009, landslides occurred every rainy season every year without any victims and serious socio-economical losses. It is apparent that the community seems to be more capable to mitigate the landslides; the key person who was in charge for this mitigation program was invited to another landslide disaster area in Tanjungsani Village at Agam Regency, West Sumatera, to transfer his knowledge and experiences for the landslide mitigation in this region. Indeed, it is considered that this system is also very applicable to be developed in several other disaster areas in developing countries, which may need several adjustments with respect to the site social and environmental characteristics.

6 Conclusion

One of the most critical considerations of disaster risk reduction in developing countries is the assurance of effectiveness and sustainability of the disaster management in such a region. A combined (hybrid) socio-technical system has been introduced to solve such problems, by addressing the importance of community participation and the simplicity of technology for landslide hazard mapping and early warning. It is apparent that this innovative approach is quite significant to improve the effectiveness of the sustainable human and social development program. Indeed, the establishment of a community task force at the village level is very important to ensure the continuity and sustainability of this proposed system.

Acknowledgements

Special thanks are directed to the Indonesian Agency of National Disaster and the British Council Delphe Program for providing financial support to carry out this pilot study. The acknowledgments are also extended to Gadjah Mada University and the Ministry of National Education for the provision of academic facilities, as well as to the research assistant at the laboratory of Environmental Geology and the laboratory of Computation at Faculty of Engineering, Gadjah Mada University.

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Capturing community influence on public preparedness

F. Petit, R. Fisher, J. Yaeger & M. Collins
Infrastructure Assurance Center, Argonne National Laboratory, USA

Abstract

Regardless of the measures put in place to prevent or mitigate them, natural and man-made hazards remain a daunting challenge for community leaders tasked with ensuring public safety. Governments and other organizations can provide services to protect and respond to their citizens' needs in an emergency, but ultimately, the relative resilience of a community relies, to a large extent, on the preparedness of the individuals living within it. While individual preparedness is determined largely by personal attributes, another important determinant is the influence of the community on the knowledge base and available resources of its members. To capture the influence that a community can have on instilling and increasing preparedness competencies in its population, Argonne National Laboratory has developed a public preparedness index. The index captures aspects such as disaster public education programs, crisis communication, public communication, citizen preparedness groups, and additional resources such as community shelters and evacuation routes/plans. This index allows community leaders to (1) better understand how well they are equipping their citizens to face potential hazards and (2) identify areas for improvement. As increased emphasis is placed on better equipping communities to face potential hazards, it is vital that those communities also understand how their actions affect the preparedness of their citizens.
Keywords: emergency management, public preparedness, regional resilience, critical infrastructures.

1 Introduction

The assessment of community resilience is complex because the term needs to characterize the resilience of organizations and infrastructures, as well as the

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110171

resilience of "softer" aspects, like the individual resilience of citizens [1]. Multiple definitions and methodologies have been developed to assess these aspects of community resilience [2–4]. While the methodologies differ in terms of their precise approach, all emphasize the need to characterize the abilities of a community to sense, evaluate, and adapt to post-disaster consequences [5]. Thus, regional resilience is properly defined as the performance of a region in managing (protecting, mitigating, responding and recovering from) an emergency or a disaster by considering the capabilities of different subsystems. These subsystems include the following:

- Ecological subsystem – combines biological and physical elements of the environment in which a community is located;
- Economic subsystem – comprises people, firms, and institutions that interact to produce, distribute, and consume goods and services;
- Governance subsystem – includes the public and private organizations that contribute to the administration of governmental functions of the community;
- Physical infrastructure subsystem – the substructure or underlying foundation or network used for providing goods and services; and
- Civil society subsystem – the formal and informal modes of social organization and collective action outside of governmental authority.

Consideration of *all* these subsystems is necessary to assess the ability of a region or system to respond to and recover from natural or human-caused hazards. However, the following elements are often underestimated or under-evaluated when considering the resilience of a region: the evaluation of the Nation's progress on personal preparedness and individual response, as well as the measure of the public's knowledge, attitudes, and behaviors in preparing for a range of hazards. The resilience of the civilian population is often referred to by different terms, such as civil society resilience, community capital resilience, community competence, social capital, and social resilience; these terms focus, to varying degrees, on the ability of the general public within a community to prepare for and respond to a disturbance. The public's *inability* to adapt, respond to, and recover from a disturbance will seriously limit the community's ability to bounce back, regardless of the resiliency of the other subsystems (listed above), because individuals are necessary for a community to exist at its most basic level and are necessary components of the other subsystems.

Argonne National Laboratory, in partnership with the Department of Homeland Security (DHS), has developed an index to characterize public preparedness that can be combined with other indices that characterize the resilience of each individual community subsystem. These indices are based on a comprehensive methodology already in use to characterize the vulnerability and resilience of critical infrastructures [2, 6]. This paper presents the main principles of this methodology and describes how it is used to assess public preparedness and the impact that a community has on increasing individual resilience capabilities.

2 Citizen preparedness

Public preparedness in an emergency is a major concern in the United States, as demonstrated by the amount of money spent to educate the public [7], as well as by the numerous awareness campaigns supported by different organizations and Web sites such as Ready.gov, 72hours.org, or AlertChicago.org [8–10].

Furthermore, numerous surveys, such as the 2009 Citizen Corps National Survey conducted by Citizen Corps, in partnership with the Federal Emergency Management Agency of DHS, have evaluated the readiness of citizens and highlighted the need for them to be better prepared to face an emergency [11]. These studies are useful in the sense that they provide statistics about the awareness and preparedness of the population and allow public officials to identify existing gaps in that preparation. Nevertheless, these studies do not provide communities with a comprehensive and consistent tool to measure how prepared their citizens are (on a community, rather than aggregate national, scale) and to define what they can do to increase their citizens' level of resilience [7].

To address this issue, different tools have been developed. One of these, the public readiness index (PRI) – developed by the Council for Excellence in Government – provides a value that allows officials to define the preparedness of a population and compare the preparedness levels of different communities [7]. While useful, this index is based on only ten questions and is focused on the community members and their current knowledge or actions, and not on their potential through community programs or resources [7]. The index does not really allow officials to define how the community can prepare the population for an emergency or identify the functions and options that a community can use to enhance the readiness of its citizens.

Thus, existing tools such as the PRI are useful in terms of the limited information they provide; however, they are not sufficient to assess, in its entirety, the citizens' level of preparation and its contribution to regional resilience. To do this, officials need to be able to measure the ability of a community to support the preparedness of its citizens. This task tends to be complex because directly measuring all the variables that support all the operational preparedness and response functions of an individual can be difficult and time consuming.

To solve these issues, the tool developed by Argonne and DHS uses proxy variables to capture the main functions and characteristics of a community that support or increase the preparation of the population facing an emergency. Instead of characterizing the ability of a community or a population to react to different specific events, the proxy variables consider the elements that contribute to increased preparation and the resources necessary to allow individuals to maximize their use of that knowledge, regardless of which individuals inhabit the community. Using these proxy variables will allow assessors to more quickly conduct the study and still reach a valid conclusion.

A top-down approach, based on the principles of functional analysis and multi-attribute utility theory [12], is used to define the main elements of the Public Preparedness Index (PPI). This index is organized into four levels of information.

- The first level corresponds to main community functions, which regroup the actions a community should take to support public preparedness.
- The second level corresponds to components, which regroup the elements a community should have to support their main functions.
- The third level corresponds to activities, which regroup the different tasks that constitute the community components.
- The fourth level corresponds to the characteristics of the activities.

The functional analysis, developed by subject matter experts (SMEs), defines a tree organization of the community elements that support public preparedness from the functions to the characteristics. Table 1 shows the eight level 1 functions and the 24 level 2 components of the PPI.

Table 1: Two first levels of the PPI.

Level 1: Functions	Level 2: Components
Disaster public education programs	• Hazard identification • Risk assessment • Hazard awareness • Training • Resources
Public information	• Crisis communication • Risk communication • Public point of contact
Public health programs	• Disease prevention/control • Food safety • Health education
Health care	• Medical assets • Surge capability • Mass casualty
Community engagement	• Public/private partnerships • Citizens groups/organizations
Warning/notifications systems	• Disaster warning systems • Public notification systems • Health alert systems
Evacuation resources	• Evacuation plans • Evacuation routes
Community shelters	• Community shelter management plan • Evacuee shelter management plan • Facilities

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Level 2 components are subdivided into their essential activities. For example, crisis communication, a level 2 component of public information (level 1), combines seven level 3 activities. One of these activities is monitoring events, which can be characterized by using five questions, which constitute level 4 information (Table 2).

The survey questions, to be answered by a yes or a no, are developed to return pertinent information that will support the calculation of the PPI.

Table 2: Levels 3 and 4 of PPI, under crisis communication (level 2) and public information (level 1).

Level 2: Crisis communication	
Level 3: Activities	Level 4: Characteristics
Monitoring of events	Following a crisis, is there a process in place to conduct: • Ongoing media monitoring? • Internet monitoring? • Exchange of information with internal and external organizations, including state health departments, etc.? • Ongoing communication with SMEs and stakeholders? • Monitoring of public opinion?

Organization of all the information that characterizes the ability of a community to support public preparedness provides officials with a means to obtain an overall index; such an index allows comparison of the preparation levels of individuals in different communities. Indeed, all levels of information can be aggregated to define the level above and, ultimately, to calculate a PPI that represents the capabilities of a community to support the preparation of its citizens.

Section 3 explains how the data characterizing public preparedness can be captured and aggregated to define a PPI that characterizes the support of a community and, ultimately, regional resilience.

3 Index methodology

The index methodology developed by Argonne and DHS allows comparison of the functions and actions undertaken by a community to increase the individual preparedness of its citizens. This methodology comprises three steps:

- Collection of data;
- Definition of public preparedness on the basis of data collected;
- Visualization of the capabilities of a jurisdiction and comparison to other like jurisdictions.

3.1 Data collection

The main components that characterize the community capabilities to support public preparedness are defined by using a top-down approach – from the functions of the community to the characteristics of activities needed to fulfill those functions. However, only the information in the fourth level (characteristics) needs to be collected. The other levels of information are calculated on the basis of the aggregation of the fourth-level characteristics. Data are collected through a questionnaire that captures the most important information characterizing community capabilities in a given jurisdiction. The questionnaire was developed in collaboration with SMEs and based on existing surveys characterizing public preparedness, individual response capabilities, and social resilience. Through the use of objective questions (e.g., the presence of a specific plan or resource), the survey ensures the collection of accurate and transparent information that can be compared and interpreted in a consistent manner. The questionnaire was developed to be completed by individuals in charge of the various service functions within a community and to be completed in a limited amount of time. The survey covers the eight core functions of a community to support public preparedness considering a possible catastrophic event. The information required to complete the PPI is collected during an on-site assessment visit; however, a self-assessed PPI score could also be derived if deemed appropriate. In this case, the data would be obtained from a survey that corresponds to the variables in the index and that could be modified to reflect future changes.

The next section describes how the data collected are used to calculate the PPI.

3.2 Calculation of the PPI

Each question (level 4), and each component and subcomponent of the PPI, is assigned a weight representing its relative importance compared with other questions/components/subcomponents in its grouping. The weights were obtained in accordance with the principles of “decision analysis,” an approach that helps manage risk under conditions of uncertainty [13, 14]. The methodology is based on a numerical representation of the value pattern obtained by comparing different elements of a jurisdiction and by using relations “better than” and “equal in value to” to define their relative importance. Another important element in this decision analysis tool is the transitivity of the ranking, i.e., if an element A is more important than an element B, and an element B is more important than an element C, then logically A will be more important than C. This approach produces a relational representation of capabilities alternatives by providing a numerical value assignment for each of its components. The weights for a set of components depend on the ranges (worst to best) that are included as options in the question set.

Table 3 shows an example of the results of that process, completed by three groups of experts, for components of monitoring an event, a subcomponent of crisis communication, which is a component of public information.

Table 3: Example of value assessments from experts (illustrative).

Public information – Crisis communication – Monitoring event							
Following a crisis, is there a process in place to conduct:	Group 1		Group 2		Group 3		Average weights
	Rank	Weight	Rank	Weight	Rank	Weight	
Ongoing media monitoring?	1	100	1	100	1	100	100
Internet monitoring?	2	90	4	70	4	80	80
Exchanges of information with internal and external organizations?	1	100	2	95	3	85	93.33
Ongoing communication with SMEs and partners?	3	80	3	75	2	90	81.67
Monitoring of public opinion data and other research?	5	70	5	65	5	70	68.33

In the index, five answers are possible to characterize the monitoring of an event. Each group of experts ranks each of these elements in relation to the others, from 1 (most important element) to 5 (least important element). If the SMEs decide that two elements have the same importance, they can give them the same rank. Subsequently, the element ranked first is attributed a weight of 100. Each group defines the weight of each other element in the grouping, considering its relative rank and importance to the element ranked first. The weights of two elements can be equal if these elements have the same importance or they can be relatively close if the elements are not of equal importance but are separated by only a slight increase in value. Conversely, the difference in weights can be large between two elements if one is considered significantly less important than another.

Table 3 shows that the three groups of experts rank ongoing media monitoring as the most important element to consider in the event monitoring variable. For Group 1, this element has the same importance as the exchange of information with internal and external organizations and is also ranked first. For all groups, monitoring of public opinion is the least important variable compared with the other possibilities. However, although the three groups ranked the variables differently, the weights defined do not vary significantly. Indeed, for this part of the PPI, the weights vary only from 65 to 100, which means that although media monitoring may be considered the most important element, the other four possibilities are also significantly important for optimal event monitoring. Finally, when all experts' ranks and weights are defined for a specific subcomponent group's level, final weights are obtained by using an average of weights. For the event monitoring variable, the final weights vary from 100 for the most important elements to 68.33 for the relatively least important. In the example, the answers are not exclusive. The best plan is the one that integrates all of the components, and it should correspond to a value of 100. It is then necessary to redefine the combined weights of all plan components to obtain a value of 100 when they are summed (Table 4).

Table 4: Final weights for event monitoring (illustrative).

Following a crisis, is there a process in place to conduct:	Average Weights	Final Proportional Weight
Ongoing media monitoring?	100	23.62
Internet monitoring?	80	18.90
Exchanges of information with yours and other organization?	93.33	22.05
Ongoing communication with SMEs and partners?	81.67	19.29
Monitoring of public opinion data and other research?	68.33	16.14
Sum	423.33	100

With these weights, it is possible to calculate a community's value for the event monitoring variable. A value of 100 is attributed to a variable when the corresponding question is answered affirmatively. A value of 0 is attributed to a negative answer. The value of the group is then obtained by using a weighted sum of all component values in a group, such as the one in Table 5.

Table 5: Monitoring event value (illustrative).

Following a crisis, is there a process in place to conduct:	Answer	Value	Weight in %	Weighted value
Ongoing media monitoring?	Yes	100	0.2362	23.62
Internet monitoring?	No	0	0.1890	0
Exchanges of information with yours and other organization?	Yes	100	0.2205	22.05
Ongoing communication with SMEs and partners?	No	0	0.1929	0
Monitoring of public opinion data and other research?	Yes	100	0.1614	16.14
Monitoring event value				61.81

The event monitoring group, in the example, integrates media monitoring, exchanges with different organizations, and public opinion monitoring. Combining the weighted values of the elements through a summation equation results in a monitoring event value of 61.81 (Table 5). The tree organization for the PPI allows assessors to use the same approach to calculate the values of the different groups of components for each level, culminating – through the additive process – in an overall PPI value. Each element in a grouping is attributed a weight using an elicitation process to define its relative importance in comparison with its pair elements. This way, the value of each group of elements in each level can be calculated by using the weighted sum of its components in the level below. Level 4 characteristics are aggregated into level 3 capabilities, level 2 components, level 1 functions, and finally an overall PPI value. Values for each of the eight Level 1 functions are aggregated to define an overall PPI, as in the example in Table 6.

Table 6: PPI (illustrative).

Public Preparedness Functions (Level 1)	Level 1 Weight	Level 1 Index	Weighted Index
Disaster public education programs	0.1587	72.38	11.49
Public information	0.1428	67.45	9.63
Public health programs	0.1111	69.63	7.74
Health care	0.0952	55.43	5.28
Community engagement	0.1033	37.85	3.91
Warning/notification systems	0.1349	60.62	8.18
Evacuation resources	0.1270	63.52	8.07
Community shelters	0.1270	57.43	6.89
Overall PPI			61.19

The disaster public education program variable was selected by SMEs as the most important of the eight functions when considering how a community impacts public preparedness, with an associated weight of 0.1587. The next most important function is the public information capability, which has a weight of 0.1428, followed by warning/notification systems at 0.1349, evacuation resources and community shelters at 0.1270, public health programs at 0.1111, community engagement at 0.1033, and finally, health care, with a weight of 0.0952.

The community characterized in this example has a fairly robust disaster public education program (hazard identification, risk assessment and hazard awareness), public health program (disease prevention, food safety, and health education), public information (risk and crisis communication, public point of contact), and evacuation resources (evacuation plans and routes). Notification systems (disaster warning systems, public notification systems, and health alert systems), health care (medical assets, surge capability, and mass casualty/ mortuary affairs support), and community shelters (community shelter management plan, evacuee shelter management plan, and facilities) have values between 50 and 60, which means that the community has diverse elements in place to fulfill these missions, but significant enhancement is still possible. Community engagement has the lowest value, 37.85, which means the community does not have robust public/private partnerships and may lack the presence of citizen groups, such as local emergency planning committees or community response teams.

By multiplying the value of level 1 functions by their weights, researchers can obtain the weighted values. The sum of these weighted values gives the overall PPI index. For example, by multiplying the disaster public education programs index (72.38) by its weight (0.1587), we obtain a weighted disaster public education programs index of 11.49. This value is added to the other weighted index values of public preparedness functions to obtain an overall PPI of 61.19 (Table 6).

This method of characterizing the capabilities of a community to support the preparation of citizens allows for consideration of how capabilities vary within the sector as a whole. A score of 100 on the PPI is not necessarily the expected level of capability for public preparedness. Rather, a score of 100 would represent an optimal community that would rarely be observed. An expected level of capability would come not from a pre-fixed number on the index, but rather from an analysis of the average preparedness score of similar communities, combined with examination of minimally accepted capabilities from within each of the Level 1 and 2 variables.

The PPI, based on a community's programs, plans, and resources in terms of public preparation, is also useful to integrate into separate programs that characterize the overall resilience of a community or an even larger geographic region.

3.3 Visualization and comparison of PPI values

Although an individual PPI is important with regard to the data it represents, it can be difficult to fully interpret without a frame of reference. For instance, does an overall PPI score of 61.19 mean that a community and its citizens are well prepared to respond to an emergency? The question cannot be answered without an understanding of how the PPI compares with other scores. The value of a PPI is strongly related to the community and its demographics and hazard profile. A comparative framework is thus necessary. Using a PPI value to compare similar communities in terms of their regional resilience can provide additional vital benefits. To facilitate comparisons between different possible actions, municipal or county officials need tools that allow them to consider possible options for enhancement, define changes in characteristics at each level, and immediately see the potential changes to the overall values of the calculated indices. The PPI can also be used to aid communities in assessing their current capabilities, as well as laying out a systematic approach to improving capabilities by targeting specific areas of weakness. The index can also be combined with other elements to characterize the resilience of a region, as described in the next section.

4 Using the PPI to assess regional resilience

Community resilience or regional resilience can be defined as the capability of a geographic location, its inhabitants, and its organizations to anticipate risk, limit impact, and recover rapidly through survival, adaptability, evolution, and growth in the face of turbulent change [14]. To fully measure regional resilience, researchers must account for all component parts (e.g., people, institutions, and organizations). To do so, they often separate the topic into two main aspects to be analyzed: soft and hard [1]. In soft aspects, consideration of the population preparedness is important. Beyond its own benefits, the PPI also complements different indices that have been developed by Argonne to assess the protection, vulnerability, resilience, and criticality of facilities, combined with information about the susceptibility of assets to specific threat types [2, 16]. By combining these indices with other tools developed to assess the resilience of individual community subsystems – leading to more specific assessment of the soft aspects of regional resilience – it is possible to form a more thorough representation of specific area resilience and of risk in general.

5 Conclusion

In a complex and interconnected world, it is vital for communities to enhance public protection and resilience. Preparing the public to face an emergency is uniquely important because safety and high quality of life are the ultimate goals of a community. Therefore, it is essential to consider how communities can support and enhance the preparedness and resilience of their citizens. The proposed PPI, based on accepted programmatic elements, allows for consideration of the particular capabilities of a community to support the preparation of its population in a global methodology to assess regional resilience.

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The contribution of human psychology to disaster management: mitigation, advance preparedness, response and recovery

C. Percy[1], Y. F. Chen[2], A. Bibi[1], D. Coles-Jordan[1], E. Dodson[1], T. Evans[1], D. Klingberg[1] & M. van der Bruggen[1]
[1]*Psychology Department, Coventry University, UK*
[2]*Department of Geography, Environment and Disaster Management, Coventry University, UK*

Abstract

This integrative review highlights the potential contribution of human psychology to disaster management, in terms of mitigation, advance preparedness, acute responses to events, and longer term psychosocial effects. The aim is not to conduct a detailed systematic review of the evidence in any one area, but rather to plot out a broad overview of the areas where work has been done, and highlight gaps where there is potential for further development.
Keywords: psychology, disaster, mitigation, prevention, preparedness, response, recovery, theory, intervention, behaviour.

1 Introduction

It has become convention to consider four distinct stages, i.e. mitigation, preparedness, response and recovery [1]. By the mitigation and prevention phase we refer to activities or perceptions relating to reducing the risks of disasters occurring, for example, to assess of reduce the risk of flooding, or to prevent chemical incidents. By the preparedness phase we mean considering, rehearsing and preparing what to do in the event of a disaster, for example, by conducting drills, exercises, and simulations. The response phase refers to activities and experiences of tackling immediate danger when a disaster occurs, for example, conducting search and rescue, or treating acute physical and psychological trauma. The recovery phase refers to activities and experiences associated with

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110181

longer term relief once immediate risk to life has passed, for example, attending to food supplies and clean water, restoring infrastructure, or recovering dead bodies. Although these disaster phases are not necessarily clearly demarcated, and they constitute phases in an ongoing cycle rather than a linear process, they are a useful way to organise any consideration of the role that psychological theory or research might play. For the purpose of this review, the terms psychology and psychological are defined broadly as pertaining to human thoughts, feelings or behaviours relevant to/during any phase of disaster.

1.1 Preparedness

Perhaps the most researched or theorised disaster phase, from the perspective of psychology, is that of preparedness. There is a large and growing body of literature in this field, which falls into two broad categories: psychological aspects of disaster preparedness in general, and preparedness for the psychological impact of disasters in particular.

There have been numerous studies investigating the meaning and subjective perceptions of preparedness for different groups individuals and groups. These studies serve an important role in identifying concerns and areas where further training in preparedness is felt to be required. These have included, for example, nurses, physicians, medical students, and emergency department directors, particularly in relation to disasters associated with bioterrorism, weapons of mass destruction, and severe acute respiratory syndrome [2–12].

A smaller number of studies have investigated perceptions of preparedness in members of the general population, including homeowners and residents in relation to terrorist attacks, and animal owners/caretakers in relation to extreme weather events [13–16]. Some studies have recognised that particular groups of people may have distinctive concerns in relation to preparedness, for example, immigrant people, chronically ill patients and elderly people in conditions of assisted living [17–19]. Studies investigating perceptions of disaster preparedness are typically descriptive, and often based on self reports. Some authors have suggested that this means of collecting data can lead to somewhat distorted picture of who needs more preparedness training [20]. An interest has now emerged in developing psychometrically valid and reliable tools to assess preparedness [21]. Although measuring subjective perceptions of preparedness is an important step towards enhancing it, it does not necessarily tell us how individuals and groups are likely to behave in the event of an emergency. A number of studies have attempted to address this by asking people about their intentions. These have investigated the stated intentions and willingness of lay volunteers, active and retired nurses, and other healthcare workers to respond in a range of disasters, including bird flu epidemic, bioterrorism and disasters in general [22–26].

Some studies have taken the further step of attempting to predict the differential behaviour of individuals and groups, based on various personal factors and attitudes [27]. For example, examining relation ships between perceived response efficacy or fear of infection, and healthcare workers' willingness to carry out their roles [28, 29]. Such studies may be used to not only predict, but potentially prevent or reduce levels of healthcare worker absenteeism in the event of a disaster [30, 31].

Moving from predicting to altering disaster behaviour brings us to a range of studies that have proposed or evaluated various interventions, drills, practices, or new technologies to enhance preparedness. The chief focus of these interventions is typically frontline response workers, including for example, nurses, emergency medical staff, medical students, nursing students, and fire-fighters [32, 33]. Simulations are an increasingly popular means of offering training to these key groups [34, 35]. New technologies are also a popular way to offer training and support for preparedness [36, 37]. There is still debate as to the best means to evaluate the effectiveness of simulations and other training exercises [38, 39]. An argument has been made that all frontline health professionals should receive disaster preparedness training, as part of the standard curriculum [40]. This would suggest that basic level of knowledge and skills is required for all professionals who are likely to encounter disaster situations. An alternative or adjunctive approach is to actively select for individuals who may possess knowledge, aptitudes or personal qualities that better suit them to leadership in disaster susceptible environments [41].

An area where there has been relatively little work published is that of developing and applying psychological theory to disaster preparedness. To achieve this requires more than describing or measuring individuals' and groups' perceptions or intended behaviours. Theory development entails developing models of the relationships between a range of variables, and crucially testing the models' ability to predict or modify behaviour. Rather few studies have taken a sufficiently broad perspective to identify the wide range of factors that may predict behaviour in disasters, perhaps because of the difficulties in obtaining data from such a wide range of actors and settings. Detailed and in depth reflections on disaster events are essential to developing theory that helps to explain not just what happened, but why. Good examples of this type of work include two detailed studies on institutional and community responses to hurricanes [42, 43].

Further refinement in the use of theoretical concepts is required to translate descriptive studies and simulations into altered disaster behaviour, for example distinguishing between the concept of disaster preparedness and disaster readiness [44]. The discipline of psychology is well placed to provide disaster researchers with well tested concepts that differentiate the broad category of perceptions/beliefs, into a more precise range of terms that include attitudes, cognitions, beliefs, subjective norms, self-efficacy, perceived behavioural control and so on[45, 46]. Very few studies have applied well developed psychological models to predicting or modifying disaster preparedness behaviours.

While the majority of studies on preparedness relate to general responses, mental health specialists are increasingly aware of the needs to prepare in advance for the specific psychological impact of disasters. Suggestions have included preparing frontline workers such as public health staff, or counselling teams to administer psychological first aid or critical incident support [47–49], and developing a mental health preparedness toolkit [50]. It has also been argued that mental health care systems should strategically involve social community support and outreach, so that links are already well established and can readily be scaled up to respond in the event of a disaster [51]. This approach may be especially valuable when the scale of disaster is so great that responding is beyond the capacity of specialist mental health professionals. As this is particularly likely to be these case in developing countries and in large scale natural disasters, it has also been suggested that developing simple psychosocial interventions should be prepared in advance to enable vulnerable communities to provide their own response [52].

A considerable effort has been expended on making plans for terrorist attacks (including the use of bioterrorism) and cyclones, hurricanes, storms and tornados. Perhaps because of the actual or anticipated impact of these on North America in recent years. Rather less work has been done on preparedness for other events, such as factory, gas pipe or oil installation explosions, ice or snow storms, and power cuts. Given the large scale of the oil spill in the Gulf of Mexico in 2010, the possibility that climate change may produce more extreme weather events and energy crises lead to more interruptions of power, these areas of research may grow in future, or need to receive more attention.

1.2 Mitigation and prevention

Relatively little work has been done to apply psychological theory and research to the mitigation and prevention phase of disasters. Clearly this is particularly relevant in the case of technological and anthropogenic disasters, where human behaviour may be a key contributing factor in events. Ergonomic, industrial and organisational psychology have potential to explain and perhaps mitigate risky or erroneous human behaviours that may precipitate disasters [53]. Increasingly, it is recognised that such crises are rarely the product of one individual's actions alone. Some authors now take a systems approach to explaining anthropogenic disasters, such as the Ladbroke grove rail disaster in the UK [54]. Research on the contribution of human behaviour to the risk of disasters has been extended beyond the level of isolated incidents, to include broader risk phenomena. For example, some work has been done on residents' and disaster survivors' willingness to take mitigation measures against the risk of floods [55] and landslides [56]. Community psychologists have argued that understanding the psychological impacts of climate change may enable us to prevent it, by modifying community and global behaviour [57]. Some authors have argued that more needs to be done to investigate why powerful individuals and groups don't act to prevent anthropogenic environmental disasters [58]. Others have recommended that we develop psychological tools to discourage 'runaway' projects that may increase risk of disaster [59].

1.3 Response

Relatively little research has been done on the response phase of the disaster cycle, perhaps because of the difficulties of collecting data at a time when saving life, limb and essential infrastructure are of greater priority. While disasters may be inevitable, they are inherently unpredictable, so planning and implementing highly structured and complex research study designs may be out of the question. For that reason, most studies in this domain rely on retrospective accounts from those involved in the response phase of the cycle, albeit collected as near in time as possible to the actual events. Examples include experiences of people involved in providing psychological first aid after disasters in India, to rescue workers after the 2001 terrorist attacks in New York, to fire-fighters involved in responding to a landslide, and to those who worked on the rescue associated with Estonia ferry disaster [60–64]. That there are numerous examples of such work is probably a consequence of the emphasis that mental health professionals place on learning from reflective practice.

Perhaps more controversial is the practice of collecting first hand accounts from those more directly involved as survivors or rescuers, who may have been exposed directly to scenes of death, physical injury or personal physical risk. Critical incident debriefing was for many years assumed to be beneficial following trauma exposure, and had even become standard practice in some settings. However, following a number of systematic reviews that suggested that it may actually have adverse psychosocial effects, it is now considered best practice to screen for and treat only those who have manifest psychological disturbance following disasters [65–67]. Key considerations in understanding this debate are how debriefing is defined, and the extent to which individuals volunteer for or are encouraged to undertake it. The range of ways in which debriefing may defined is broad, and may include, for example, brief, single session, individual or group discussion, extended repeated and in depth examination of concerns, or vivid reliving of traumatic events. It has been suggested that pressuring individuals to participate in such activities may be deleterious to mental health, even when the intention is benign. A lack of clarity in the debate may lead some to conclude that it is probably best to leave exposed individuals to deal with direct or vicarious trauma in their own way, unless they actively seek psychological intervention, or exhibit clear symptoms of psychological disturbance. This has not, however, precluded researchers collecting data on experiences of disaster responders, for the purpose of research rather than therapy. Studies have been conducted on the subjective experiences of nurses following earthquake, rescue workers after terrorist attacks, train crashes and freeway collapse [68–71]. While participating in these accounts may or may not have psychological benefit or detriment for survivors and responders, they certainly have value in informing us about the nature of human experience on the response phase. Providing ethical concerns can be fully addressed, it may be worth making use of relatively unstructured qualitative and inductive designs to collect more data on these experiences. The use of novel technologies such as internet blogs may offer a means to collect contemporaneous data, where the infrastructure is available.

1.4 Recovery and longer term psychosocial effects

There have been a great many studies on the longer term psychosocial effects of exposure to disasters, corresponding the phase of disaster typically referred to as recovery. Most work has been done on the impact of disasters on survivors [72–75]. Some work has begun to differentiate the special needs of particular populations, for example children [76–78]. However, relatively little work has considered the longer term psychosocial impact of disasters on women [79, 80], and on pre-existing chronic illness or disability.

There is also a growing recognition of the deleterious effects of vicarious trauma, for example on emergency services and military personnel [81–84]. Some research to date has recognised longer term psychological damage in people exposed to potentially traumatic situations, focusing on the prevalence and treatment of conditions such as Post Traumatic Stress Disorder (PTSD) [69, 72, 83, 85–87]. PTSD is increasingly recognised as a common and debilitating mental disorder, and considerable effort has been expended developing and researching treatments for those affected [88–94]. However, what is not fully understood is *why* and *how* PTSD occurs in some people but not in others. The literature to date has tended to focus on studying individuals who are very distressed and have sought therapeutic intervention. This has arguably led to a pathologisation of human responses to trauma. A number of authors have pointed out that developing symptoms of PTSD is the minority response to traumatic events, and that most people so exposed display remarkably little psychopathology. It is suggested then that *resilience* is the more common response to trauma, and, just as there are individual differences in vulnerability to PTSD, there may also be numerous routes to resilience [95–100]. These pathways may be mediated by a combination of personal, psychological and social or contextual factors [101–103]. For example, psychological factors that have been linked to resilient response to potentially traumatic events include personality, optimism, extraversion, openness to experience, conscientiousness, low neuroticism, altruism, affect regulation, ego defences, controlled coping, learned helpfulness, effective behaviours despite fear, positive emotions, e.g. gratitude, love [101, 102, 104–106]. Social and contextual factors including bonding, teamwork, pre-existing relationships, social institutions, and organisational patterns and roles may also have a protective or buffering effect [101, 102, 104–106].

2 Conclusions

Few studies or interventions have applied psychological theory to disaster and related behaviours, despite the existence of numerous well established theories which have been used to predicting and modify behaviours in other contexts, such as health. There is scope for more application of psychological theory to the mitigation and prevention phases, at both a macro and micro level.

Studies assessing disaster preparedness often rely on self reports of subjective perceptions. More work is needed to test the predictive validity of perceptions and intentions, and to develop valid and reliable measures of disaster preparedness. There is still debate as to the best means to evaluate the effectiveness of simulations and other training exercises. More research is needed to identify the most valid and reliable means to evaluate preparedness interventions.

There is a need for more work on psychological aspects of the response phase, notwithstanding controversy about critical incident debriefing. This work could rely more on inductive qualitative designs and use novel data collection techniques. Psychological first aid doesn't necessarily have to be wholly reactive and/or provided by specialist professionals. If community members are integrated into existing healthcare systems, they may be trained to offer simple but effective support. Work needs to continue on identifying factors that promote resilience, and psychosocial interventions need to promote these factors to enhance resilience.

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Development of the Analytical Hierarchy Process (AHP) method for rehabilitation project ranking before disasters

M. Yadollahi & M. Z. Rosli
Faculty of Civil Engineering, University of Technology, Malaysia

Abstract

Various proposals for rehabilitation of different structures are presented to decision makers in the forms of rehabilitation proposals. Managers and decision makers have to be aware of the consequences of selecting particular structures as rehabilitation alternatives. The Analytical Hierarchy Process (AHP) as a powerful and simple method can help decision-makers evaluate proposals against a set of weighted criteria and use a data evaluation form to verify that the necessary data have been provided. This study presents a model based on AHP methodology to develop the strategy for ranking non-similar structures against multi-hazard conditions. For this purpose, a quantitative matrix consisting of numerical values for disasters and structures can easily represent the ranking of structures for any purpose such as rehabilitation or fund allocation. It is an approach that describes how good decisions are made rather than prescribes how they should be made. This model offers opportunity to change criteria and modify judgments. A case study for ranking of four types of structures in a road network against four common types of disaster is presented to show the applicability of the proposed model. The results of the study show the relative importance weights of the road structures. The achieved normalized numeric results (for each group of structure) indicate the importance of these structures in the road network.
Keywords: risk analysis, disaster management, Analytical Hierarchy Process (AHP), decision making, rehabilitation.

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110191

1 Introduction

In recent years, the world has witnessed a significant increase in losses associated with natural disasters. Both socio-economic and climatic factors are contributing to this upward trend in disaster losses. Managers and decision makers have to be aware of the consequences of selecting particular structures as rehabilitation alternatives. Various proposals for reconstruction or rehabilitation of different structures present to project managers and decision makers in the forms of rehabilitation proposals. In last decade, the vulnerability assessment of critical infrastructure in road network has been investigated by many researchers and decision makers from different points of view. Jenelius et al. [9] introduced important indices for network links to estimate the vulnerability index. Menoni et al. [10], using a set of parameters measuring the response capacity of lifelines exposed to earthquakes, proposed an assessment tool for measuring the response capacity of lifelines exposed to earthquakes. In the field of landslide, Cardinali et al. [5] proposed a model to evaluate landslide hazard and risk. Same methodologies for evaluating the risk of other hazards for road network infrastructures were done by other researchers. To find the quantitative amount of risk, it is common to introduce a risk index for specific hazard and try to quantify this index. Kannami [7] and Schaerer [8] applied almost the same methods to achieve this goal for hazard of flood and avalanche respectively.

This research proposes a model based on Analytical Hierarchy Process (AHP) to develop the matrix of different criteria for different disasters. Based on mathematics and psychology, AHP was developed by Thomas L. Saaty [1] in the 1970s and has been extensively studied and refined since then. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analysed independently. AHP is a method where the objectives, attributes, or elements of a decision are formatted in a hierarchy and weighted according to the degree of preference the decision makers assign to each element. This method usually helps the problem of multicriteria decision making in the situation in which there exists a prioritization of criteria. It does not take for granted the measurements on scales, but asks that scale values be interpreted according to the objectives of the problem. In this study, relative importance criteria is evaluated first for different structures and then based on the weights of disasters, new weighs will import to the model. Disaster Weights are numerical values evaluated for each structure when the influence of specific disaster is considered. The result of multiple sets of pair-wise comparisons at each level is a weighted value hierarchy, with all of the priorities in the decision concisely captured and expressed as numerical values. Therefore, there is quantitative matrixes consist of numerical values for disasters and structures that can easily represents the ranking of structures for any purposes such as rehabilitation or fund allocation decision making. It is an approach that describes how good decisions are made rather than prescribes how they should be made.

2 Methodology and formulation of the developed AHP model

The analytic hierarchy process is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, the AHP helps the decision makers find the one that best suits their needs and their understanding of the problem. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time. In making the comparisons, the decision makers can use real data about the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations [1].

Natural disasters are infrequent events with the potential to cause significant economic losses and human suffering. Generally, in real situations, every structure is exposed to more than one type of disasters; although most of the researches in the field of risk management have focused on risk of only one disaster, such as earthquake, and only one structure, such as buildings or bridges. A comprehensive risk analysis includes assessments of various levels of the hazard, as well as of consequences to structures should the hazard occur. Disasters are linked not only to hazardous events but also to the vulnerabilities of the exposed elements and capacities within the society to cope with them. This paper presents a practical methodology for rehabilitation project ranking against different hazards using AHP concept. This methodology is divided in three parts:

- Hazard Identification: To score hazards for specific type of structure based on basic AHP method;
- Structure Vulnerability Assessment: To score vulnerability of structures against specific type of hazard based on basic AHP method;
- Weight Assignment Process: To build the multi-dimensional matrix using two pre-mentioned AHP matrixes to rank the structures against hazards.

If there rare more than one type of structures, then the rank of each structure is assumed as the total risk for the specific structure and is calculated as below:

$$Rank_{Total} = Risk_{Total} = W_{Structure}.Rank_{Structure} \quad (1)$$

where $\boldsymbol{W_{Structure}}$ is the relative importance weight of structure in comparison to other structures and $\boldsymbol{Rank_{Structure}}$ is quantitative value of risk for specific structure against different hazards. Both of the mentioned factors range from 0 to 10, so $\boldsymbol{Rank_{Total}}$ is a number from 0 to 100 and represents the relative ranking of specific structure in comparison to other non-similar structures against different disasters. According to general definition of risk, which is a function of hazard (criticality) and vulnerability, we can easily show that:

$$Rank_{Structure} = V_{Total}.H_{Total} \quad (2)$$

where $\boldsymbol{V_{Total}}$ is the total vulnerability of specific structure against all hazards (disasters) and $\boldsymbol{H_{Total}}$ is the quantitative amount of ranking hazards affecting the structure in a specific region. In the following sections the way of calculating the qualitative value of these two parameters is presented.

2.1 Hazard identification and weight assignment process

Hazard identification involves the process of describing the hazard in its local context and provides a description and historical background of the potential environmental hazards that could impact the structures [2]. This process results in a clarification of the magnitude of hazard that may pose a threat to the structure. The hazard identification process thus includes an examination of past disasters and the potential for the future disasters within the specific region.

For the purpose of ranking hazards affecting the structures in order of the importance for mitigating their effects, a hazard index has been assigned (see table 1) with 10 indicating the highest priority for considering mitigation measures and 1 indicating the lowest priority (Highest, High, Medium, Low, Lowest). Hazard index takes into account the anticipated *Frequency of Occurrence* (see table 2) and specific *Consequences of Impact* (see table 3) [3].

Table 1: Hazard index scale.

Hazard Index Ranking				
Impact → / Frequency of Occurrence ↓	Catastrophic	Critical	Limited	Negligible
Highly Likely	10 (Highest)	8 (High)	8 (High)	6 (Medium)
Likely	10 (Highest)	8 (High)	6 (Medium)	4 (Low)
Possible	8 (High)	6 (Medium)	4 (Low)	4 (Low)
Unlikely	6 (Medium)	4 (Low)	2 (Lowest)	2 (Lowest)
Highly Unlikely	4 (Low)	2 (Lowest)	2 (Lowest)	2 (Lowest)

Table 2: Frequency of occurrence.

Highly Likely	Near 100 percent probability in the next year.
Likely	Between 10 and 100 percent probability in the next year, or at least one chance in the next 10 years.
Possible	Between 1 and 10 percent probability in the next year or at least one chance in the next 100 years.
Unlikely	Less than 1 percent probability in the next year or less than one chance in the next 100 years.
Highly unlikely	Little to no probability in next 100 years.

Table 3: Consequences of impact.

Catastrophic	Multiple deaths, complete shutdown of facilities for 30 days or more, more than 50 percent of property is severely damaged.
Critical	Multiple severe injuries, complete shutdown of critical facilities for at least 2 weeks, more than 25 percent of property is severely damaged.
Limited	Some injuries, complete shutdown of critical facilities for more than one week, more than 10 percent of property severely damaged.
Negligible	Minor injuries, minimal quality-of-life impact, shutdown of critical facilities and services for 24 hours or less, less than 10 percent of property is severely damaged.

Four types of hazards will be evaluated in this study. For each of the hazards, a simple and relative index introduced in order to evaluate the score for the criticality of the region for specific structure. This evaluation is based on rapid risk assessment and, obviously, for more detailed evaluation, other factors need to be assessed. The hazards is introduced based on the most important disasters occurred in road network as a practical sample for developing the model. In the following sections, hazards and relative factor for hazard evaluation is introduced.

2.1.1 Earthquake

Earthquake ground motion may be characterized by either [4]:

- The peak ground acceleration expected at a site in a given period of time, from which the design spectrum may be drawn based on several simplifying assumptions, or
- By two points on the design spectrum from which the remainder of the spectrum may be drawn using fewer, but more realistic, assumptions than in above.

In this study to simply the characteristics of earthquake and seismic behaviour of structure region, Peak Ground Acceleration (PGA) which mostly represents the ground motion intensity is selected as seismicity index. According to a United States Geological Survey (USGS, 2004), the peak acceleration is the maximum acceleration experienced by a particle during the course of the earthquake motion. Thus, PGA is the maximum acceleration of ground experienced by the particle during the course of the earthquake motion. Table 4 shows the relative score for different range of PGA. In detailed evaluation of structures, it is preferred to determine seismicity based on a more precisely specified location.

Table 4: Seismic vulnerability score.

Seismic Vulnerability Score					
A=PGA/g	A < 0.2	0.2 ≤A<0.25	0.25≤A<0.30	0.30≤A<0.35	0.35≤A
Score	2	4	7	9	10

2.1.2 Landslide

Landslide hazard refers to the natural conditions of an area potentially subject to slope movements. It is defined as the probability of occurrence of a landslide of a given magnitude, in a pre-defined period of time, and in a given area. Landslides were classified according to their type of movement, and their estimated ages, degrees of activity, depths, and velocities. Landslide hazard (H) depends on the frequency of landslide movements (F) and on the landslide's intensity (I).

Table 5 shows how we defined landslide hazard for each landslide hazard zone (LHZ), combining frequency and intensity. Landslide frequency was estimated using four classes, based on the number of landslide events (of the same type) observed within each LHZ. Landslide intensity was defined in four classes, based on the estimated volume and the expected velocity. Levels of landslide hazard using a two-digit positional index. The right digit shows the landslide intensity (I) and the left digit shows the estimated landslide frequency (F) [5].

Table 5: Landslide frequency and intensity classification.

Estimated Landslide Frequency	**Landslide Intensity**			
	Light (1)	Medium (2)	High (3)	Very High (4)
Low (1)	1 1	1 2	1 3	1 4
Medium (2)	2 1	2 2	2 3	2 4
High (3)	3 1	3 2	3 3	3 4
Very High (4)	4 1	4 2	4 3	4 4
Landslide hazard for each LHZ: Landslide intensity, grouped into four classes: light (1), medium (2), high (3) and very high (4), and the estimated landslide frequency, grouped into four classes: low (1), medium (2), high (3) and very high (4)				

Different indicators have been introduced to score the landslide vulnerability according to literature. The hazard indicators were separated into two groups: conditional factors and triggering factors. Some important conditional factors are as: slope angle, land use, geology, soil, geomorphology, slope length, drainage density and internal relief. Apart from the abovementioned conditional factors, also two triggering factors were taken into account: precipitation and seismicity. These factors are generally considered as appropriate factors for landslide susceptibility assessment at a general scale [6]. Selecting the appropriate vulnerability and hazard index depends on the field of research and structure characteristics. In this study, in the field of road transportation structures, physical vulnerability index can be introduced in order to score and quantify the vulnerability value (see table 6).

Table 6: Landslide vulnerability scores.

Hazard		**Vulnerability Score (Expected Damage)**					
		Minor		**Major**		**Total**	
Low ↑	**1 1**	A 1 1	1	F 1 1	2	S 1 1	3
	1 2	A 1 2	1	F 1 2	2	S 1 2	4
	1 3	A 1 3	2	F 1 3	3	S 1 3	4
	2 1	A 2 1	3	F 2 1	4	S 2 1	4
	1 4	A 1 4	3	F 1 4	4	S 1 4	5
	2 2	A 2 2	4	F 2 2	5	S 2 2	5
	2 3	A 2 3	4	F 2 3	5	S 2 3	6
	3 1	A 3 1	4	F 3 1	5	S 3 1	6
↓ High	**3 2**	A 3 2	5	F 3 2	6	S 3 2	7
	2 4	A 2 4	5	F 2 4	6	S 2 4	7
	3 3	A 3 3	6	F 3 3	7	S 3 3	8
	4 1	A 4 1	6	F 4 1	7	S 4 1	8
	4 2	A 4 2	7	F 4 2	8	S 4 2	9
	3 4	A 3 4	7	F 3 4	9	S 3 4	10
	4 3	A 4 3	8	F 4 3	9	S 4 3	10
	4 4	A 4 4	8	F 4 4	10	S 4 4	10
Vulnerability, the expected damage to the elements at risk. A=superficial (aesthetical, minor) damage; F = functional (or medium) damage; S = structural (or total) damage.							

2.1.3 Flood

Yasuo Kannami [7] proposed the flood vulnerability score as a function of exposure, basic vulnerability and capacity. He proposed the Flood Vulnerability as the below equation:

$$Flood\ Vulnerability = \frac{Exposure \times Basic\ Vulnerability}{Capacity} \tag{3}$$

Table 7 shows average number of killed people and events in some past floods. Based on latter research, estimated average killed people per event is selected as an indicator to categorised the flood vulnerability. The related scores for different ranges are presented in table 7 [7].

Table 7: Flood damage classification.

Class	Criteria (No. of people of one event)	Countries covered	No. of Events (N)	No. of killed people (K)	Average killed people per event (KperN)	Vulnerability Score
Low	~ 100	177 (100%)	2775 (88%)	54831 (13%)	19.8	**3**
Middle	101 ~ 1000	54 (31%)	345 (11%)	97408 (22%)	282.3	**5**
High	1000 ~	15 (8%)	41 (1%)	280721 (65%)	6846.9	**10**
Total		177 (100%)	3161 (100%)	432960 (100%)	137.0	

2.1.4 Avalanche

By definition, avalanche hazard is the expected frequency of damage and loss as the result of an interaction between an avalanche and objects and persons. The term contains two elements, (a) the frequency of an encounter, which may be defined as the probability of an encounter in a given period of time, and (b) the nature and magnitude of the resulting damage, which in turn is a function of the nature of the avalanche. The avalanche-hazard index is a number that reflects the seriousness of the avalanche danger to structures of road. Table 8 shows the idealized classes of avalanche were assessed for their effect on road structures [8].

Table 8: Avalanche hazard classification.

Avalanche Class	Density in motion	Frontal Speed	Flow Depth	Vulnerability Score
	Kg/m^3	m/s	m	
Powder snow	3-15	5-20	>2.5	**1**
Slough	100-400	1-6	0.2-0.6	**2**
Light snow	30-250	6-50	0.5-2.0	**3**
Deep snow	90-300	6-50	2.0-2.5	**7**
Plunging snow	10-100	20-60	>2.5	**10**

Powder snow: Powder snow that crosses a road at a speed of up to 20m/s and deposits snow less than 0.1 m deep produces conditions on the road similar to those resulting from blowing snow. In most cases, the resulting damage tends to be minor.
Slough: This term defines slow avalanches of flowing snow which stop on the road. Characteristically, they either deposit deep snow on one shoulder and cover part of the road or they cross the road and stop at the opposite edge, depositing less than a 0.3 m depth of snow. This type of avalanche often originates from a short steep slope and vehicles tend not to be damaged, because of the small size and low speed of the avalanche, and are normally able to drive either round or through the deposited snow.
Light snow: Flowing avalanches of light snow go beyond the road and deposit depth of snow between 0.3 and 1.0 m. Cars could be pushed off the road by the action of such snow but would not be buried. Avalanches must be classified as of the plunging-snow type if vehicles could be damaged by falling down a steep slope after being hit by the snow.
Deep snow: Flowing avalanches that deposit snow to a depth of more than 1 m on the road are classified as the deep-snow type. Vehicles affected could either be buried or be swept off the road and damaged when falling down a steep slope. The occupants would probably be injured or killed when their vehicle was crushed by, or moved with, the avalanche. Death from burial in the snow is also a possibility.
Plunging Snow: Avalanches of dry, flowing snow and/or powder snow which cross roads at high speed after falling over long, steep slopes and cliffs come into this category. They are extremely destructive because of their high speeds.

2.2 Structure vulnerability assessment

Structure vulnerability is a condition or process resulting from physical and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard. The goal of the vulnerability assessment in this study is to estimate the consequences of hazards which affect on a specific structure and assign a weight to structure vulnerability against a specific disaster. For this propose, the total vulnerability as any structure, is calculated as below:

$$V_{Total} = \sum_{i=1}^{n+2} a_i v_i = a_1 v_{Earthquake} + a_2 v_{Landslide} + a_3 v_{Flood} + a_4 v_{Avalnche} + a_5 v_{Rockfall} + a_6 v_{Structural} + a_7 v_{Stability} \quad (4)$$

where $\boldsymbol{a_1}$ to $\boldsymbol{a_7}$ are the relative weights of each hazards, $\boldsymbol{V_i}$ are the vulnerability scores of the structures against related hazards and $\boldsymbol{n}$ is the number of hazards. In this equation, $\boldsymbol{V_i}$ are estimated based on tables 4, 6, 7 and 8 for relative hazards. Two other vulnerability score, $\boldsymbol{V_{Structural}}$ and $\boldsymbol{V_{Stability}}$ are estimated for each type of structure based on physical condition of structures. $\boldsymbol{a_i}$ is estimated based on pair-comparison analysis. The analysis is come from questionnaire survey results.

2.3 Questionnaire survey design based on pair-comparison analysis

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analysed independently. The elements of the hierarchy can relate to any aspect of the decision problem, carefully measured or roughly estimated, anything at all that applies to the decision at hand [1]. Table 9 shows the fundamental scale for pair-wise comparisons. In the current study, a pilot survey was conducted with experienced risk managers and engineers to validate the final questionnaire. The questionnaire was then administered by interview with 80 selected risk and disaster practitioners within the ministry of road and transportation and some other consultant companies who are primary participants in disaster risk management area.

Table 9: The fundamental scale for pair-wise comparisons.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment sightly favour one element over another
5	Strong importance	Experience and judgment strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible orders of affirmation
Intensities of 2, 4, 6 and 8 can be used to express intermediate values.		

The main important goals of the questionnaire survey were to answer the following questions:

- *What are the related weights of four aforementioned hazards to any specific structure in the affected area?*
- *What are the relative impotence weights of four structures in the road network?*

To find the weighs for these two questions, the responders were asked to compare the hazards in pair and assign weights for their comparison according to the table 9.

3 Case study: road infrastructures

The presented methodology for ranking non-similar structures against various hazards using AHP developed method has been implemented for 4 types of structure in road network against 4 mentioned hazards. The structures are the main vulnerable components of road network which any malfunction, damage or removal from service would significantly affect public safety, national security, economic activity or environmental quality.

3.1 Relative weights of hazards

These structures are bridges, tunnels, retaining walls and buildings. The selection of the structures and hazards is just a sample for case study to show the capability of the proposed model. Obviously, in real situations, it is necessary to evaluate the most important disasters in a specific region which threat the structures. In the following section the results of pair-comparison analysis using the help of eigenvector prioritization method is presented.

Bridges

$$B_1 = \begin{bmatrix} 1 & 4 & 1 & 5 & 5 & 1 & 1/2 \\ 1/4 & 1 & 1/4 & 2 & 1 & 1/2 & 1/2 \\ 1 & 4 & 1 & 5 & 5 & 1 & 1/3 \\ 1/5 & 1/2 & 1/5 & 1 & 1 & 1/2 & 1/4 \\ 1/5 & 1 & 1/5 & 1 & 1 & 1 & 1/2 \\ 1 & 2 & 1 & 2 & 1 & 1 & 1/2 \\ 2 & 2 & 3 & 4 & 2 & 2 & 1 \end{bmatrix}$$

Retaining Walls

$$B_3 = \begin{bmatrix} 1 & 1/3 & 1/2 & 1/2 & 1/3 & 1 & 1/2 \\ 3 & 1 & 3/2 & 3/2 & 1 & 3 & 2 \\ 2 & 2/3 & 1 & 1 & 2/3 & 1 & 3/2 \\ 2 & 2/3 & 1 & 1 & 2/3 & 1 & 3/2 \\ 3 & 1 & 3/2 & 3/2 & 1 & 2 & 3/2 \\ 1 & 1/3 & 1 & 1 & 1/2 & 1 & 1/2 \\ 2 & 1/2 & 2/3 & 2/3 & 2/3 & 2 & 1 \end{bmatrix}$$

Tunnels

$$B_2 = \begin{bmatrix} 1 & 1/5 & 5 & 7 & 5 & 1 & 1/3 \\ 5 & 1 & 7 & 7 & 5 & 7 & 3 \\ 1/5 & 1/7 & 1 & 1 & 1 & 1 & 1/3 \\ 1/7 & 1/7 & 1 & 1 & 1 & 1/3 & 1/3 \\ 1/5 & 1/5 & 1 & 1 & 1 & 1/5 & 1/5 \\ 1 & 1/7 & 1 & 3 & 5 & 1 & 1/2 \\ 3 & 1/3 & 3 & 3 & 5 & 2 & 1 \end{bmatrix}$$

Buildings

$$B_4 = \begin{bmatrix} 1 & 4 & 4 & 4 & 4 & 1 & 3/2 \\ 1/4 & 1 & 1 & 1 & 1 & 1/4 & 1/2 \\ 1/4 & 1 & 1 & 1 & 1 & 1/4 & 1/2 \\ 1/4 & 1 & 1 & 1 & 1 & 1/4 & 1/2 \\ 1/4 & 1 & 1 & 1 & 1 & 1/4 & 1/2 \\ 1 & 4 & 4 & 4 & 4 & 1 & 3/2 \\ 2/3 & 2 & 2 & 2 & 2 & 2/3 & 1 \end{bmatrix}$$

According to the numeric values in the above matrix, relative weights of hazards based on equation 5 are as table 10.

Table 10: Relative weights of hazards.

Indices	a_1	a_2	a_3	a_4	a_5	a_6	a_7
Bridge	0.20701	0.07194	0.20107	0.04908	0.07139	0.13065	0.26886
Tunnel	0.14820	0.42950	0.05050	0.04060	0.03980	.010150	0.18980
Retaining Wall	0.07200	0.22480	0.13930	0.13930	0.20252	0.09628	0.12569
Building	0.27714	0.07209	0.07209	0.07209	0.07209	0.27714	0.15735

3.2 Relative weights for structures

In order to compare the structure together and to achieve the appropriate ranking, it is necessary to find the relative weights of structures. This means that how the structure removal affect the performance of the network. In this part, 50 questions were designed to find the appropriate weight of structure in the network. The results are represented as matrix No. B_5 and table 11. The results are the average (mean) of the results from questionnaire (CR= 0.0471).

$$B_5 = \begin{bmatrix} 1 & 7/3 & 9 & 9/2 \\ 3/7 & 1 & 7 & 5 \\ 1/9 & 1/7 & 1 & 1/3 \\ 2/9 & 1/5 & 3 & 1 \end{bmatrix}$$

Table 11: Relative weights for structures.

Structures	Bridge	Tunnel	Retaining Wall	Building
Relative Weights of Structures (W_{St})	0.5217	0.3327	0.0445	0.1011

4 Analysis and discussion

The methodology has been tested against the judgment of experts and, to the extent possible, against records from several past disasters. However, limited and incomplete data about actual hazards damage precludes complete calibration of the methodology.

4.1 Reliability of the survey

With the help of PASW18, Cronbach's alpha was calculated to test the internal consistency reliability of the generated scale. The alpha reliability coefficient normally ranges between 0 and 1. The closer alpha is to 1 the greater the internal consistency reliability of the criteria in the scale. The values for bridges, tunnels, walls and buildings are 0.896, 0.801, 0.714, and 0.755, respectively. All alpha values are greater than 0.7, indicating that all reliability coefficients are acceptable and the internal consistency of the criteria included in the scale is excellent. Consistency Ratios for pairwise analysis are shown in table 12. All the values are less than 0.1 which indicate acceptable judgments of the responders.

Table 12: Consistency Ratio (CR).

Structures	Bridge	Tunnel	Retaining Wall	Building
Consistency Ratio (CR)	0.0696	0.08266	0.01558	0.00171

4.2 Ranking analysis

In order to rank the rehabilitation projects based on the AHP method described in previous section, the normalized form of equation (1) is introduced to rank the specific structure against different hazards as below:

$$Rank_{Total} = W_{St}\left(\frac{\sum_{i=1}^{n+2} s_{St}a_i}{\sum_{i=1}^{n+2} s_{max}a_i} \times 100\right).\ H_{Total} \tag{5}$$

In this equation, $\boldsymbol{S_{max}}$ is the sum of all vulnerability score for specific structure. By feeding the survey results into PASW18, structure ranking values can be calculated using the formula above. Based on the magnitude of the $\boldsymbol{Rank_{Total}}$ index, the ranking results for a group of structures can be evaluated.

5 Conclusion

One challenge facing project managers and decision makers in rehabilitation planning for hazard mitigation is that of selecting appropriate and most vulnerable structures. Once the hierarchy based on AHP method is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time. In making comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. In road transportation area, this leads to find a general ranking of the most vulnerable structures against multi-hazard situation. Ranking the structures based on developed AHP method needs gathering data about vulnerability indices for related hazards and components of structures. This can be simply done by preparing rapid visual screening or other methodologies for vulnerability assessment of structures. Since AHP method offers an actual measurement system, it enables one to estimate relative magnitudes and derive ratio scale priorities accurately. It offers opportunity to change criteria and modify judgments. The normalized relative importance weights of structures are 0.5217, 0.3327, 0.0445 and 0.1011 for bridges, tunnels, retaining walls and road buildings respectively. Therefore, it can be used to make direct resource allocation, conduct cost-benefit analysis, design and optimize systems.

Acknowledgement

The writers would like to express their gratitude to the research grant awarded by the Research Management Center (RMC), Universiti Teknologi Malaysia.

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An application of enterprise risk management in the marine transportation industry

M. D. Abkowitz & J. S. Camp
Department of Civil and Environmental Engineering, Vanderbilt University, USA

Abstract

Establishing the current status and future direction of an organization's enterprise risk management (ERM) practice demands an ability to benchmark the existing level of performance and prioritize where risk mitigation actions are warranted. This requires a systematic and holistic approach that can identify and assess every "reasonably foreseeable risk", compare risks on a common basis for prioritization of "hot spots", and evaluate the effectiveness of candidate risk mitigation strategies. Designing and implementing a management tool that organizations can utilize for this purpose is challenging, given that it must be comprehensive in nature, yet easy to apply.

This paper describes the development of such a tool and its subsequent application to a large marine transportation carrier. In this application, two separate ERM activities were undertaken; one focusing on a functional line of operations throughout the entire organization (information technology and cyber security), and the other involving all activities associated with a specific geographical region that serves as an operations hub. The resulting risk scenarios, assessments and candidate mitigation strategy evaluations are described and discussed.

The paper also shares several lessons learned that are important for organizations interested in developing and applying ERM tools. These include how to overcome the challenges of: (1) structuring a framework for identifying enterprise risks and creating corresponding scenarios that are all inclusive, (2) creating an appropriate system for associating the likelihoods and consequences with various risk scenarios, and (3) developing a protocol to enable evaluation of the benefits and costs of potential risk mitigation strategies that are developed in response to those risks that have been deemed to warrant

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110201

priority attention. Each of these challenges was encountered in the marine transportation carrier study.

Keywords: enterprise risk management, marine transport, cyber information security, risk identification, scenario analysis, risk mitigation, risk assessment, hazard analysis, disaster management.

1 Introduction

Risk management has existed for centuries, beginning as far back as the *Code of Hammurabi* [1]. Today, in light of a spate of recent natural disasters, large-scale accidents and malicious acts, enterprise risk management (ERM) has become a favorite expression among organizations in both the private and public sector. Consequently, many organizations have instituted what they believe to be ERM as part of daily operations. Gates and Hexter [2], in surveying 271 financial and risk executives, reported that over one-half of respondents (56%) are making efforts to develop and implement some form of "enterprise risk management" strategy within their organizations, with another 35% of those surveyed positively disposed towards using ERM. Corporate governance, regulatory requirements, and an increased understanding of strategic and operating risks are motivating ERM implementation in these organizations [3].

While many firms are utilizing the term enterprise risk management, their approaches range from managing risks for a specific purpose to a company-wide implementation involving the commitment of considerable financial and human assets [4, 5]. In reality, it is only the holistic approach, one that includes all risk-related elements, hazards and scenarios, internal and external to the firm, which deserves the ERM label.

Central to any risk management activity is risk identification, which historically, has been heavily influenced by known problems or prior incidents. This reactionary mode typically limits the amount of creative thought that is invested in identifying allpotential scenarios of what could go wrong. One popular approach to overcome this deficiency is to identify risks through compartmentalization, where each process, department or organizational group is viewed as a unique entity [6, 7]. Other approaches abound, such as those that categorize risk in terms of the recipient, whether it be workers, customers, the community, the environment, or an organization's physical assets [8].

While there may be variation in identification and categorization approaches, most importantly there is general agreement that enterprise risks encompass a variety of considerations, both within and external to an organization, affecting numerous stakeholders. This is an encouraging sign in terms of the potential for creating a holistic decision-support framework that can serve as the basis for establishing an ERM practice for any organization.

2 ERM decision-support framework

In the work described herein, an ERM decision-support framework designed to address the aforementioned considerations is put forward for discussion and applied in a case study environment. It is comprised of the following sequential steps.

1. Using risk and hazard categories, develop scenarios representing reasonably foreseeable events
2. Assign likelihood and consequence values (risk scores) to each scenario
3. Estimate annual "risk costs" and conduct absolute and comparative analyses
4. Identify and evaluate risk mitigation strategies

A more detailed explanation of each of these steps appears below.

2.1 Scenario development

The task of developing appropriate scenarios begins with the definition of a set of ERM risk categories that is holistic in nature, but can be segmented into specific risk areas that are intuitively appealing and practical to apply. Table 1 presents the structure developed for this purpose.

Table 1: Enterprise risk categories.

Internal	External
1.Operational	**1. Operational**
a. Product/Service Quality	a. Social, Political & Economic Relations
b. Employee/On-Site Contractor Relations	b. Customer, Supplier, and Off-Site Contractor Relations
c. Financial Management	c. Malicious Acts
2. Information Systems	**2. Information Systems**
a. Technology\Hardware & Software	a. Technology\Hardware & Software
b. Proprietary & Personal Information Management	b. Proprietary & Personal Information Management
3. Physical	**3. Physical**
a. Facility Infrastructure & Physical Assets	a. Infrastructure, Transportation, & Resource Availability
b. Employee Health and Safety	b. Environmental & Natural Hazards
c. Environmental Releases	

At the top level of the hierarchy, risk categories are defined first by whether they are considered internal or external in nature. The terms "internal" and "external" identify the origin of the hazard with respect to the organization in addition to providing an indication of the extent to which an organization can control the referenced risk. Some risk categories can be associated with both internal and external risks; however, the hazards that fall into these categories would be different. For example, an information security breach that originates as a computer virus sent by an email to an employee would be considered an external risk, whereas an employee copying files or stealing proprietary company information for personal gain would be considered an internal risk, even though both events involve information breaches that compromise the organization's intelligence and data systems.

Beyond the division of internal and external risks, risk categories are segmented into three principal dimensions: (1) operational, (2) information systems, and (3) physical. Operational risks are defined as those that relate to how business is transacted within the organization. These include risks associated with financial decisions, resource management, and relationships with employees, contractors and customers. Information system risks include computer hardware and software, as well as all "intangible" assets associated with those systems (i.e. data, employee personal information, bank records, and customer accounts). Among an organization's physical assets are buildings, stock and equipment. Employees and their wellbeing (i.e. health and safety) also falls into this category, along with those risks associated with environmental releases by the organization or by others (external) that may adversely impact business operations.

Within each risk category reside a number of different hazards that can threaten the organization. For example, in the External – Physical – Environmental and Natural Hazards category, hazards could include events such as tornadoes, earthquakes, floods, wildfires and heavy snowfall. Because the events associated with each hazard will differ, it is important to capture these circumstances in terms that can easily be envisioned for consideration and analysis. The most promising format for doing so is development of event scenarios for each hazard.

To fully understand the potential risks associated with each hazard, multiple scenarios must be evaluated. These scenarios should represent the range of events that are "reasonably foreseeable" that an organization may experience. The basis for determining these event scenarios is based on answering the question, "What could go wrong?" To capture the full breadth of possibilities, the developed scenarios should represent incremental levels of impact severity, ranging from events with minor to catastrophic outcomes. Referring to the previous discussion, for a tornado hazard, at one end of the spectrum, a scenario might be a tornado warning for a two-hour window during the business day where the organization is situated, although a tornado does not subsequently materialize. On the other end of the scenario spectrum might be a direct hit to the facility by an F4 tornado that completely destroys the building and causes human casualties. Of course, other scenarios can be constructed to represent tornado events that fall in between these extremities.

What is critical at this stage is that all reasonably foreseeable risks have been identified and characterized in the form of scenarios for each hazard in each of the risk categories. Therefore, as the risk assessment process progresses, one has confidence that the organization will experience no surprises because it was systematic and comprehensive in how it approached risk identification.

2.2 Risk scoring

To evaluate the risk associated with each scenario, two important components must be taken in consideration: 1) the likelihood (frequency) that the scenario could occur and 2) the consequences if the scenario does occur.

Recognizing that there will typically be a large number of scenarios and limited availability of loss prevention data, this necessitates a scoring system that can elucidate reasonable responses to these two risk inputs. As a result, the semi-quantitative risk scoring method shown in figure 1 was developed. The first scale in figure 1 corresponds to establishing scenario likelihood. Note that the selection options range from occurrences expected to be extremely rare to those that may happen several times within a given year. If a Level 1 or Level 5 frequency is assigned to a scenario, then a supplemental table is provided that enables the user to become more precise with their frequency estimate (e.g., 1 in 100-year event; daily event).

The bottom two scales in figure 1 are used for consequence estimation. Here, property/asset impacts are separated from those that describe impacts to human health. The reason for this segmentation is that participants engaged in this process typically consider property/asset impacts on a monetary scale, whereas impacts to human health are more commonly quantified in terms of fatalities and injuries. Although there is a desire to combine all impacts into a single economic unit, that computation is done later as an internal feature that is derived from available "value of statistical life" literature [9, 10].

Frequency

Level	1	2	3	4	5	6
	Extremely Rare	Rarely	Occasionally	Annually	Semi-annually	Frequently
Description	Occurs less than once in 25 years	Occurs less than once every 10 years, but more than once every 25 years	Occurs less than once every 5 years, but more than once every 10 years	Occurs less than once every 5 years, but more than once per year	Occurs at least once per year, but less than once per month.	Occurs at least once per month.

Consequence - Impacts on Property/Assets

Level	1	2	3	4	5
Description	Minimal	Moderate	Significant	Severe	Catastrophic
	Between $0 and $100	Between $100 and $1,000	Between $1,000 and $10,000	Between $10,000 and $100,000	Over $100,000

Consequence - Impacts on Human Health

Level	1	2	3	4	5
Description	Minimal	Moderate	Significant	Severe	Catastrophic
	Persons are treated on site for minor injuries and released, if any impact at all	Level 1 plus one or more persons requiring emergency room treatment	Level 2 plus one or more persons requiring hospitalization	Level 3 plus fatalities of 1 to 5 persons	Level 3 plus fatalities of more than 5 persons

Figure 1: Risk scoring method scales.

2.3 Risk analysis

Using the results from the previous step, an estimated "risk cost" can be computed by multiplying the scenario likelihood by its corresponding economic consequences. A convenient way to report this information is on an annual basis, which is simply derived by converting likelihood into annual terms (i.e. an event that is expected to occur once every 25 years is assigned an annual likelihood of 0.04) and then multiplying it by the event consequence cost.

There are two popular ways to present these results. One is a table showing the annual risk cost for each scenario. The other is in the form of a “heat map”, essentially a graph where one coordinate represents the scenario likelihood and the other represents the economic consequence. We find both approaches to be useful in understanding the risks associated with each scenario. Whereas the table allows for a rank ordering in purely economic terms, the heat map provides insight into whether a scenario with a significant risk cost is being driven by a high probability, low consequence event or a low probability, high consequence event. This has ramifications when it comes to applying resources to risk mitigation both in terms of priority and expenditure.

Evaluation results can be aggregated to the decision-maker’s level of interest, with the scenarios being the most detailed level. At some point, it will be important to compile the risk scores for all scenarios in a hazard class, so that the risk associated with different hazards can be compared (e.g. Is my risk greater for tornadoes or earthquakes?). At an additional level of aggregation, risk scores can be compared among different categories (e.g. Am I more exposed to employee health and safety risk or natural hazard risk?). Finally, at the highest level of aggregation, the total risk cost for the enterprise in a given year can be established. This provides a means for examining the vulnerability of the organization as a whole, while also serving as a baseline against which to measure progress as mitigation strategies are implemented.

2.4 Mitigation strategy evaluation

The identification and evaluation of risk mitigation strategies is a bit more complicated than one might imagine. While it is logical to focus development and deployment of mitigation strategies on those scenarios, hazards, and/or risk categories that represent the largest economic burden to the organization, a couple of important considerations may prevail. First, not every mitigation strategy will necessarily produce a sufficient reduction in risk cost to justify its investment. Secondly, many mitigation strategies will offer risk reduction benefits that accrue across multiple scenarios, hazards and risk categories. As a result, a structured assessment process is needed.

To address these considerations, an economic benefit cost analysis approach using net present value was adopted. The implementation costs associated with a prospective mitigation strategy can be estimated in a straightforward manner, assuming adequate information on capital and operating costs, investment lifetime and discount rate. However, deriving the economic benefit (i.e. reduction in risk cost) requires returning to the scenarios where the mitigation strategy in question is intended to reduce scenario risk, either by diminishing likelihood, consequence or both. In each of these instances, the decision-maker is asked to re-score under the assumption that the candidate mitigation strategy has been implemented. The net change in risk cost from original scoring and then re-scoring is used as the benefit metric in determining the value of the proposed mitigation strategy. Of course, it is up to the decision-maker to determine whether the associated benefit/cost meets a threshold for strategy investment.

3 Case study application

The methodology, as previously described, was applied to a large marine transportation carrier. In this application, two separate ERM activities were undertaken; one focusing on a functional line of operations throughout the entire organization (information technology and cyber security), and the other involving all activities associated with a specific geographical region that serves as an operations hub.

3.1 Scenario development and scoring

The scenario development process involved working directly with company executives to identify risk categories and hazards that the organization faces, including what could go wrong in each instance. Care was given to define a set of scenarios that ranged from those likely to produce relatively benign impacts to those with the potential for catastrophic outcomes. A particular challenge was to limit the number of scenarios such that participants would not find the scoring process to be burdensome without sacrificing coverage of relevant risks. Once the scenarios were defined, participants were asked to score the scenarios using the scales presented in figure 1.

3.2 Risk analysis results

Risk analysis results for the IT and cyber security application appear in table 2, expressed in annual risk cost. Only those hazards with annual risk costs in

Table 2: Risk analysis results – IT and cyber security.

Hazard Categories		Annual Risk Costs ($)
Tier 1 - Greatest Risk (Greater than $10M)		
	Cyber - Information Leakage (Employee, Cust., and Proprietary Data)	$14,802,000
Tier 2 - High Risk ($2.5M - $10M)		
	Networks - Unauthorized Access/Security Breach (PC)	$4,630,000
	Physical - Snow	$3,264,000
	Software - Upgrades (Failure or Lack Thereof)	$3,232,000
Tier 3 - Moderate Risk ($1M - $2.5M)		
	Networks - Network Failure or Crash (Internet)	$2,113,000
	Cyber - Backups/System Redundancy Failure	$2,014,000
	Physical - Fire (Forest, Range, Wildland)	$1,969,000
	Physical - Tornado or Strong Winds	$1,947,000
	Hardware - Denial of Service/Usage (System Shut Down or Crash)	$1,866,000
	Physical - Earthquake	$1,865,000
	Cyber - Information Theft (Employee, Customer, and Proprietary Data)	$1,854,000
	Cyber - Website Hacking	$1,553,000
	Physical - Hurricane/Tsunami	$1,422,000
	Physical - Offices	$1,137,000
	Networks - Internet Abuse (Band Width, Illegal Sites, etc.)	$1,112,000

excess of $1 million are shown, an arbitrary threshold for presentation purposes. Note that leakage of employee, customer and proprietary data dwarfs the others in terms of annual risk cost, representing a problem in excess of $10 million a in terms of annual risk cost, representing a problem in excess of $10 million a year. The rationale behind this concern is that if business confidential information falls into the hands of a competitor, this can have a significant impact on the company's competitive edge and therefore its bottom line. The annual frequency of occurrence is estimated to be quite high for most scenarios falling into this hazard category (see heat map in figure 2), perhaps an indication of how recent WikiLeaks activity has exposed the vulnerability of information espionage.

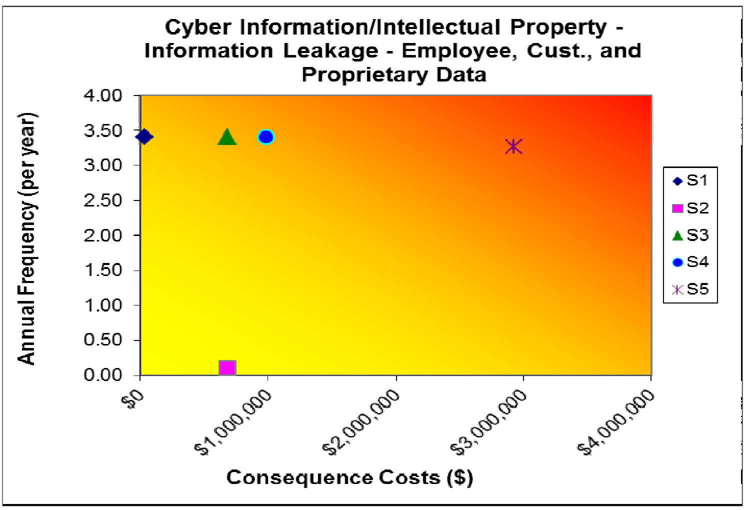

Figure 2: Employee, customer and property data leakage scenario heat map. S1 – An associate sets up an email rule to automatically forward received email to a personal email account of theirs or others. S2 – A system is set up to forward email to non-corporate domain email accounts (e.g., Gmail, Yahoo). The individual receiving the email leaves the organization and joins a competitor, yet continues to receive the former organization's email, which may be confidential business. S3 – An associate copies information to a personal device (e.g. memory stick, USB drive) for purposes of using the information for business on their home computer. This device is not encrypted and is inadvertently lost. S4 – An associate discovers information of value on a system or report, and shares that information with friends or relatives for their personal gain. S5 – An associate bypasses the corporate data retention policy for email, documents, etc. and makes unauthorized electronic or hard copies.

Hazards with annual risk costs in excess of $1 million are shown in table 3 for the operating region application. This is accompanied by figure 3, which presents a heat map showing scenarios associated with external malicious acts, the hazard deemed as having the largest annual risk cost for the operating region.

Table 3: Risk analysis results – operating region.

Hazard Category		Annual Risk Costs ($)
Tier 1 - Greatest Risk (Greater than $10M)		
	N/A	--
Tier 2 - High Risk ($2.5M - $10M)		
	External - Malicious Acts - Terrorist or Disgruntled Employee	$4,536,000
	Internal - Information Systems - Internet Abuse	$4,012,000
Tier 3 - Moderate Risk ($1M - $2.5M)		
	External - Physical - Tornado or Strong Winds	$2,373,000
	Internal - Physical - Employee Health (Slip, Trip, Fall)	$2,133,000
	External - Physical - Impaired Air Quality	$1,942,000
	External - Economic - Market Conditions	$1,640,000
	Internal - Physical - Facility Damage (Random Incident)	$1,210,000

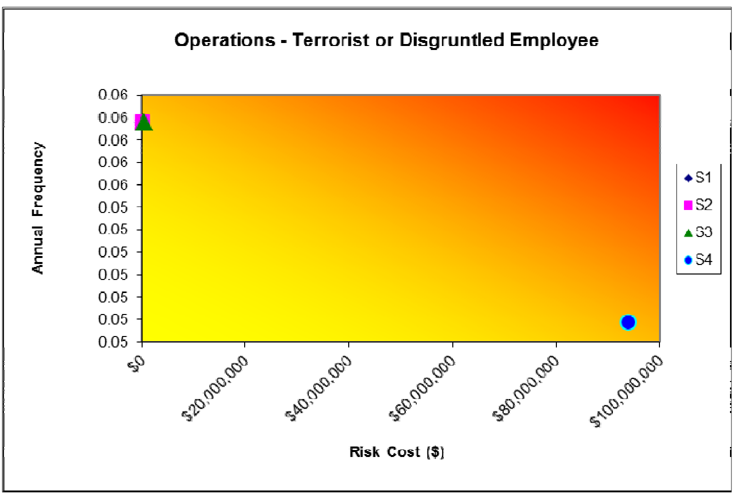

Figure 3: Malicious act by terrorist or disgruntled person scenario heat map. S1 – You have recently fired an employee who the organization viewed as violent and emotionally unstable. S2 – Your facility or one adjacent to yours receives a letter threatening a bomb attack or release of a chemical or biological agent; OR an employee receives a package that contains a white powder. S3 – A small explosive device or mildly toxic chemical/biological agent is discharged or released inside your facility or a nearby facility. The device/ chemical impacts a portion of your facility. S4 – Employees in your facility are being held hostage by a gunman and shots have been heard OR an explosive device is discharged inside your facility that causes serious damage.

Of particular interest in reviewing this heat map is that the overall annual risk cost is driven almost exclusively by Scenario 4, a situation in which a gunman or explosive device renders considerable harm to people located in the facility, resulting in multiple fatalities and injuries. This low probability, but high consequence event can be evaluated by a risk manager as either being too remote a possibility to worry about, or a situation where the consequences could threaten the very existence of the business. Depending on this perspective, reducing this risk could be a high priority or not warrant much attention.

One area of interest is the extent to which a functional line within an organization and the employees who utilize that resource view the same risks. Figure 4 displays the annual risk costs for IT hazards that were common to both the IT functional line and the operating region. Note that in most instances, the party responsible for the resource (the IT group) recognized the significance of certain risks that were considered rather benign by the operating region. This is not surprising given that many of these hazards are integral to the functional line's services and may not be transparent to the end user. However, in one instance, internet abuse, the disparity in the opposite direction is striking. One could surmise that the IT department has underestimated the amount of internet abuse practiced by employees on a routine basis. This underscores the need to involve multiple stakeholders in the ERM process so that both awareness and risk score accuracy are enhanced.

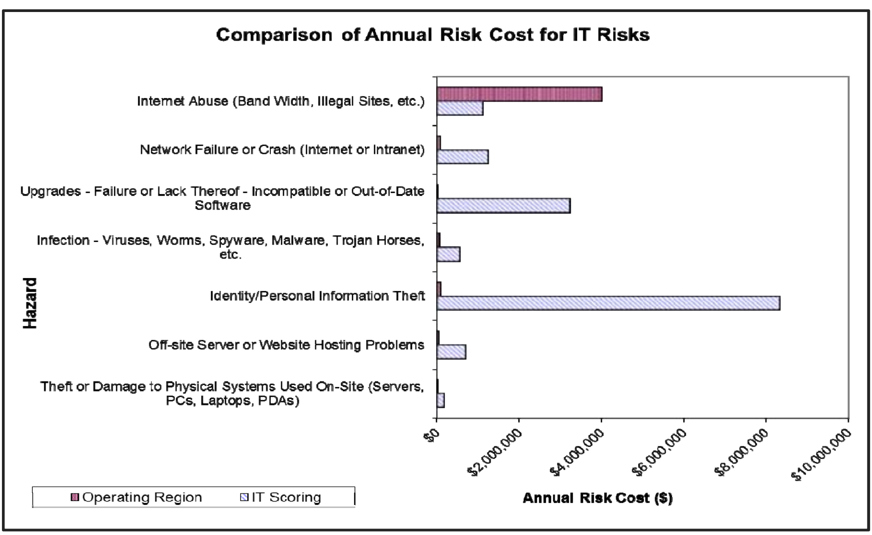

Figure 4: Comparison of IT and operating Region Responses.

3.3 Mitigation options evaluation

Deployment of the mitigation strategy benefit-cost analysis is underway. Although results cannot be reported as yet, the approach is outlined below.

Participants are being asked to use the risk analysis results to determine the importance of mitigating risks belonging to certain categories, hazards and scenarios. This spawns a set of mitigation strategies worthy of evaluation. The process for determining the benefit-cost of each candidate strategy is illustrated in table 4. Three prospective mitigation strategies are shown (enhance emergency evacuation plan; improve firewalls and security; implement weather warning system), along with their respective annual implementation cost. The net risk cost reduction from re-scoring is shown within the table by strategy and hazard. The total risk cost reduction, when aggregated across all relevant hazards, represents the overall strategy benefit. The benefit-cost ratio is then computed. Note that, in this illustration, strong justification exists to implement improved firewalls and security, whereas the other two strategies are unlikely to justify further consideration.

Table 4: Illustration of mitigation strategy benefit cost analysis.

			Risk Cost Reduction ($)					
	Mitigation Options	Implementation Cost ($)	Cyber Info Leakage	Networks - Unauthorized Access	Physical - Snow	Physical - Flood	Total Risk Reduction ($)	B/C Ratio
M1	Enhanced Emergency Evacuation Plan	$100,000			$10,000	$40,000	$50,000	0.5
M2	Improved Firewalls and Security	$2,000,000	$5,000,000	$240,000			$5,240,000	2.62
M3	Weather Warning System	$750,000			$150,000	$200,000	$350,000	0.47

3.4 Discussion

The case study applications yielded several observations regarding implementation of the ERM framework which are currently being used to revise the methodology. They include the following:

1. To gain cooperation and focus from participants, it is important to limit the number of scenarios for consideration.
2. Scenario descriptions must be carefully reviewed for accuracy and ease of understanding prior to their use.
3. The number of levels in scoring tables should be limited so as to elucidate differences in likelihood and consequences without being overly precise.
4. Respondents should be allowed to designate “Do Not Know” so that arbitrarily assigned scores do not bias the evaluation outcome.
5. When possible, likelihood and consequence scores should be quality-controlled by assessing “reasonableness of results” relative to empirical loss data.
6. When large differences in individual scores occur for the same scenario, an attempt should be made to reconcile the disparity.
7. Having a sufficient number of participants involved in the scoring process is essential to achieving representative results.

4 Conclusions

An ERM methodology has been devised and field-tested whose design is to capture all reasonably foreseeable risks using a protocol that is considered practical and achievable. Results to date indicate that it can serve as a valuable tool, provided that care is given to how risk categories, hazards and scenarios are defined, the manner in which scenario likelihood and consequence is estimated, how the results are interpreted, and the process from which mitigation strategies are developed and assessed. Our research is continuing to refine the methodology and to expand its use to other organizations, both in the private and public sector.

Acknowledgements

This research was sponsored by the Intermodal Freight Transportation Institute at the University of Memphis through the federal Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The authors are grateful for this support as well as the assistance provided by employees of the marine transportation carrier described herein.

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Section 4
Surveillance and early warning systems

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Wireless network sensors that are energy efficient for monitoring and early warning

V. Ferrara
Department of Information Engineering, Electronics and Telecommunications, Sapienza University of Rome, Italy

Abstract

Wireless sensor networks can be a convenient monitoring system for wide areas, because they are economically advantageous and they should be more specialized than remote sensing. Many different systems have been proposed as wireless sensor networks. Some networks are based on an IP protocol, as a web of objects. However, other solutions can be adopted when mostly the network is realized outside of an internet framework or when the internet connection can be limited at a few nodes. Architectures based on ZigBee protocol are an evident example. The IEEE 802.15.4 standard communication protocol of Wireless Personal Area Network (WPAN) defines the best characteristic of low-power, but limited data rate. It is a good candidate as the standard communication for many applications and monitoring activities. After the introduction of trends in the field of low power sensors networks, the design of a particular monitoring network will be presented: the early-warning of flood river control and intervention management.
Keywords: WSN, low power, low voltage.

1 Introduction

Disaster management needs a detailed monitoring of the environment, theatre of calamitous events, together with the actual human and material resources that are ready for intervention. Monitoring can be realized in different modes. For wide areas, as a country or province, remote sensing is more convenient. For non large terrestrial surfaces, distributed sensors are cheaper and more specialized. In the case of sensors at ground, they must detect both parameters of interest and the terrestrial coordinates where measurement was carried out. If it mounts a sensor

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110211

in a mobile structure, this must include a GNSS (Global Navigation Satellite System). In some case, coordinates of relative or differential localization should be transmitted. If a sensor is fixed in a known position, its terrestrial coordinates are associated with the identification number of sensor. Distributed on the territory, the totality of sensors realizes a network. If the link is wireless, the network is a Wireless Sensors Network (WSN). Design of like network depends from area extension, maximum distance of link permitted from standard communication, maximum number of nodes, economical convenience and budget. After the introduction of trends in the field of sensors networks, the design of a particular monitoring network will be presented: early-warning of flood river control and intervention management. The aim of the article is to put in evidence advantages of sensor network in terms of detection specificity, maintenance, reduced consumption, energetic autonomy. The last ones are characteristics that derive from electronic technology development: they augment the freedom degrees in the position of nodes. It must be adopted harvesting energetic sources that are efficient. Many and different are the problems that must be resolved and challenges faced, but performances of designed system are promising, in terms of specialized monitoring, integration with other monitoring forms in a wider and complete management system and competitive cost.

2 Sensor networks

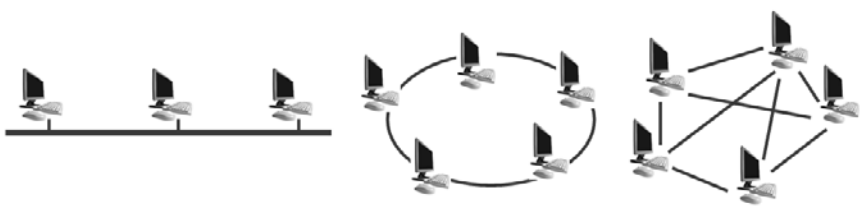
Monitoring of a wide geographical area can be efficiently obtained by remote sensing. This is a consequence of the high altitudes of satellite orbits which allows links to the most remote and least accessible areas. Even satellites with low earth orbit (LEO), that move at altitudes within 160 and 1600 km (below radiation belts, the named Van Allen belts), observe a large territory in any case. Other than geostationary orbit, the elliptical orbits are covered in a rotation time that depends from the altitude. So, monitoring continuity is not satisfied introducing a temporal resolution of satellite as time duration between two observations of the same area. Temporal resolution varies from hours to days and it can be the real limit of this monitoring methodology, in special mode when scenarios are that of emergency management. Satellite orbit, together with sensor characteristics determine the spatial resolution of the detection, like the amount of area covered by each pixel of the picture. Obviously, low orbits allow higher resolution.

In order to discover and to identify: elements, objects, materials, substances at ground, adequate spectral resolution must be used for sensing of sufficient range of the electromagnetic spectrum. At the same mode it need a suitable value of the radiometric resolution, i.e. the sensitivity for recording variations in the electromagnetic spectrum, measured in number of bits.

Alternative detections of data, complementary to remote sensing in some cases, and essentials for calibration of same remote sensing, could be realized. In effect, a network of at ground sensors constitutes valid system, when the continuity of a specific territorial area monitoring is the fundamental characteristic [14, 15].

We refer to a monitoring system that includes nodes and communication lines. One special node is the main node: the command and control station, the headquarters, where all data join from each remote node. In a complete form, nodes collect: sensors or actuators, communication device, power source and electronic digital management system as a microcontroller. Each node manages four phases: detection, data elaboration, transmission and reception of external inputs. In some cases a node can be only of re-transmission: it is missing of sensor unity and absolves the function of communication transit node. All nodes and communication lines together account for a network. Its structure is meshed preferably: each node communicates with other node different from main node normally. So, data is arriving to the main node from a remote node along a path that crosses other nodes. If each node is connected with all other nodes, the network is named completely connected. But increase of cost orients to realize a mesh network no completely connected in general.

The communication link can be wire type, but wireless technology is more convenient in the case of territorial area monitoring activity.



a) b) c)

Figure 1: Some network topologies: a) bus, used e.g. in the communication standard 802.3 (Ethernet wired); b) ring, adopted in the standards 802.5, FDDI, RPR 802.17; c) mesh no completely connected.

Generally, at ground, sensor networks cover a more limited area than that observed from a satellite. The reason resides in the number of nodes that increases considerably with the area augmentation. But low cost of single node design (it foresees more reduction in the near future) and of its maintenance allows optimization of network. At the present, nodes can be built in more small dimensions involving that device with very low power consumption. This feature, the technology of effective communication and increased performance computing, opens up new prospects for innovative architectures for the control and monitoring. In particular, the low power feature allows you to design your own power source based on the method of harvesting [9–11]. So, remote sensor location is independent by public power line and topology of mesh design can be defined by actual requirement of measure and by radio link only.

In any case, each node is identified univocally in the mesh. Its location is an element of identification, whereas measured quantity can be the same for different nodes. Generally it used a number identifying single node. This is similar at internet applications, where node identification is based on Internet Protocol (IP).

Many different systems have been proposed as wireless sensors networks. Moreover, operating area dimensions and size of devices classify the systems as: ubiquitous sensor networks, smart dust, smart objects.

2.1 Smart dust

Smart dust [1] is composed of large number of tiny electronic systems that measure the quantities as temperature and humidity over an area by use of spreading mode. Dispersion of these tiny unities in the area can be realized by using air flow for example. At the moment limitations for smart dust are in the communication method and computational capability.

2.2 Smart objects

The specificity of smart objects it is pointed out by different synonyms with which are named: web of objects, web of things, Internet of Things, cooperating objects. They are node in a web context. In any case a smart object includes: sensors and actuators interacting with the physical world, microprocessor which elaborates data collected from the sensors, communication devices for transmitting detected data and for receiving input from other smart objects and finally power source that provides the electrical energy.

Many are their applications: analysis of complex properties of air pollution, more simple parameter detections as temperature inside to containers, detection in the car parking, etc. Web service technology is used for this activity of monitoring. Web services are defined as communication between business servers. In the other words, at web site end, a user activates the web service functionality of smart objects, without requiring translation. It invokes a web service that does not reside in the World Wide Web of the user. In fact, web services provide an intermediary that allows travel agent server and another server to exchange data in owner framework. In order to realize a web service built on mechanisms that require communication bandwidth and processing power lower, a protocol more simple than SOAP (Simple Object Access Protocol) should be adopted. An alternative for smart objects is the Representational State Transfer (REST): a more lightweight architectural model which describes applications distribution. When data, like humidity, are transferred from server to client need only the knowledge of data representation (e.g. decimal representation) and the server-client connection. More information makes the model heavy, with consequences on communication bandwidth and power consumption.

An example of web service system for smart objects has been realized by Pachube web site. It is a system RESTfull, carried out around REST architecture. Users can submit data of sensors in a network on Pachube server. Moreover they can store and upload the same data. In order to use Pachube web site as an intermediary, company provides Application Program Interface (API) open, based on RESTfull model. Server absolves requests by means of HTTP protocol and formulates transfer of data by means a custom version of XML markup language, the Extended Environments Markup Language (EEML), or equivalent JSON or the more simple RSS or ATOM. Peculiarity of these markup languages is the inclusion in the tags of “environmental” information that are associated with the data: location coordinates, range of data values, unit of measure.

It can use a different technology of communication, but conveniently it should be based on Internet Protocol [2]. The choice of communication standard depends from many factors, whose one is the network extension (WLAN, WPAN, respectively wireless local area network and wireless personal area network). In case of smart objects a fundamental feature is low-power consumption. So, it is convenient to use IEEE 802.15.4, standard communication protocol of WPAN [6, 7], with best characteristic of low-power, but limited data rate: 250 Kbits/s. Some studies have been realized for this standard communication, implemented on specific devices in order to assess the increase in power consumption [3, 4]. Normally, this augmentation depends from the state and from the transition between two states.

Some specificities of smart objects make you want to use IP in open and interoperable form. So, companies in the fields of telecommunications, automation systems, etc., like Cisco, Ericsson, Atmel, Sun Microsystems, Dust networks and others, have founded in September 2008 an alliance to promote and to develop IP for Smart Objects: the IPSO alliance [5]. From initial 27 founding members, the alliance counts now about 50 members.

2.2.1 ZigBee

In any case, the identification by IP address of each network node is not the only way. Obviously, this is the choice in an immediate and organic web context.

Other solutions can be adopted, when mostly the network is realized outside of internet framework or when the internet connection can be limited at few nodes. In the last case, only these nodes will have an interface towards internet world. For many applications WPAN and low power IP architecture is evaluated too excessively with, no advantage. Consequently, there are architectures, like ZigBee, based on protocols that don’t use IP.

ZigBee is a communication system, a network layer on top of the IEEE 802.15.4 standard, which includes PHYsical (PHY) and Message Authentication Code (MAC) layers. Transmission bands are in ISM (Industrial, Scientific and

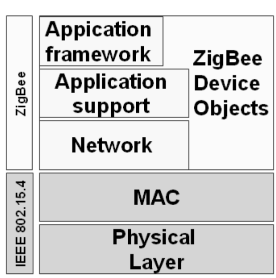
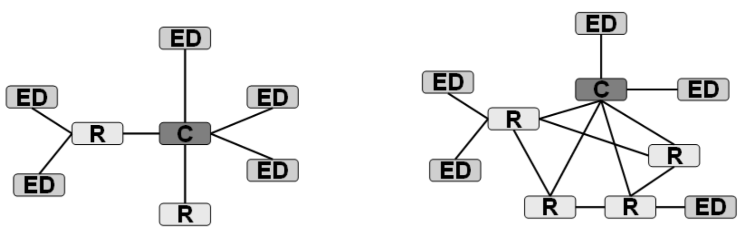


Figure 2: ZigBee protocol stack.

Medical) band: 2.4 GHz, for international applications with 250 Kbits/s maximum throughput, 915 MHz, adopted in USA with maximum throughput of 40 Kbits/s and 868 MHz, in Europe at 20 Kbits/s bit-rate. Modulation is Bi-Phase Shift Keying (BPSK) for bands 868 and 915 MHz and Offset quadrature phase-shift keying (OQPSK) for that at 2.4 GHz. Access mode is the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA): nodes occur if channel is free before transmission. But when transmission needs a low latency, the GTS (Guaranteed Time Slots) is the access mode.

Figure 2 shows its protocol stack. In particular the network layer is equivalent to IP layer of the architectures based on IP. At this layer competes routing and addressing. Application support layer is equivalent to the transport layer of IP architectures. There are three different ZigBee devices: Pan coordinator, router and End Device. Pan coordinator is one per network: it manages all nodes and it bootstraps the network. Router is an intermediate device that communicates with another node. Instead pan coordinator and routers are FFDs (Full-Function Device). End Device is a RFD: Reduced Function Device, showing lower functionality than coordinator and router. End devices communicate only with their router. Figure 3 shows classical topologies that can be implemented for the network: star and mesh. But, when two nodes must be connected between them, a more simple peer-to-peer topology could be realized.



a) b)

Figure 3: Usual network topologies for ZigBee: a) star; b) mesh. Nodes ED, R and C denote respectively: End Devices, Router and Coordinator.

ZigBee transmits in two different modes: broadcast and unicast. The broadcast method sends data packet toward all nodes with expensive procedure. In unicast mode packets are sent only to the addressed node.

A commercial project which uses ZigBee protocol requires that the company participates, as membership, to Zigbee alliance, whereas for non-commercial projects the specifications can be downloaded from Zigbee web site [8]. In any case a custom protocol can be implemented on these transmitter-receiver devices. Custom design solution should be adopted when there are conveniences in terms of power consumption and loss. Alliances, like IPSO and ZigBee, are advantageous for interoperability and support, but they impose dependencies often: users are constrained to revise devices for innovating release, developed from the main companies of alliance.

3 Case study: river monitoring

In order to control the flood of a river, we designed a monitoring system based on ground sensors network. Its main function is as an early warning in the case of an incipient flood event. As the smart objects, our network nodes include: sensors, microcontroller, transceiver and power supply.

Functions of a node are: measurement of environmental parameters (as temperature, humidity, level of river, detection of images), data elaboration, automatic transmission of eventual early warning, image transmission if requested. Actually, we provided in the prototype the implementation of image acquisition and its local elaboration for evaluating early warning. Essential components of a node are: PIC32MX360F512L microcontroller, MRF24J40MA IEEE 802.15.4 standard compliant radio frequency transceiver, OV7710 CMOS VGA colour CameraChip^{TM}. Microcontroller and transceiver are Microchip devices. The single-chip video/imaging camera device is an Omnivision image sensor. MRF24J40MA is a PCB module (Printed Circuit Board) and its dimensions are 1.1x0.7x0.03 inches. It includes an integrated PCB antenna that has need an area around 1.2 inches be kept clear of metal objects. Transceiver module interfaces PIC microcontroller via 4-wire serial SPI interface.

The optical control of a target, one per node, allows automatic evaluation of flood warning condition. This method can be coupled with detection of surface water level of river that uses e.g. laser based system. OV7710 device can acquire also panoramic image. This one will be transmitted toward control centre if coordinator requires it. Low rate of IEEE 802.15.4-2003 standard limits the transmission of total image to on-demand only. Moreover the re-transmission along the nodes of the chain could determine reception delay. This delay can be decreased by imposing alternative standard communication. The number of these different transmitters must be evaluated when you define operative aspects of design.

Monitoring system will be organized by installing a network of these devices along the course of river. The distance between two nodes depends from sensitivity and output power of transceiver. There are transceivers that allow radio connection at one kilometre of distance. The greater is the distance the higher is energetic consumption of node. In order to obtain minimum number of energetically autonomous nodes, it is necessary a compromise. In our prototype design, transceiver covers about 100 meter of distance, but we collocate nodes about at 30-50 meter between them. This is allowed because the production cost of single node can be very low. River monitoring network topology, shown in figure 4, assumes a line form. If other nodes, no-contiguous, are in visibility, jump is permitted in the case communication link at node fails.

Three protocol stacks are proposed from the transceiver for using in a specific network configuration: MiWi Peer-to-Peer, MiWi and ZigBee. In the case of a simple communication, with a couple of nodes, MiWi Peer-to-Peer is the protocol stack more convenient. For MiWi protocol stack, all nodes use the same multiple access in the channel. ZigBee protocol stack is more complete and complex among three protocols.

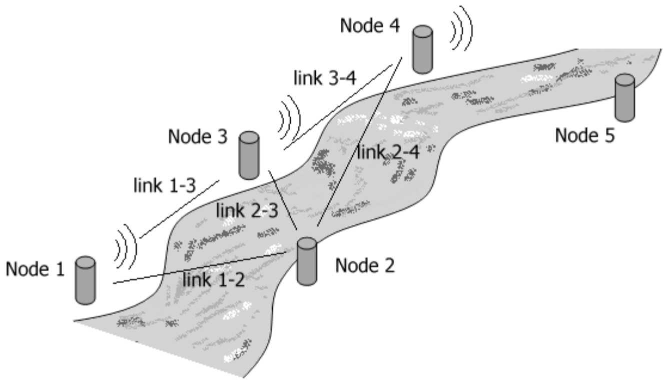


Figure 4: Topology of network is a simplified mesh. Normally a linear radio communication link connects progressively the nodes 1-2, 2-3, etc. But if a link fails, alternative connections are permitted.

In order to decrease energetic consumption of each node, a custom protocol has been used for this simplified mesh network.

At start, coordinator node evaluates requests of all nodes and assigns PAN ID: 16 bits identification number that defines the RF channel used from the network. After the start phase, coordinator node is placed in the LOCK state and network configuration is stored in a non-volatile memory. Reset of system can be realized by three different ways: soft reset, half reset and full reset. By using of soft reset system restart from statements saved in the memory. If it imposes half reset, all data are cancelled except for PAN ID that assures same nodes configuration. Finally, full reset starts a new network re-assignation. Coordinator checks the RF channel, considering communication noise also. Minimum test time is about ten seconds. After check, the coordinator starts half reset. Single node can require a channel hop, among 15 channels that are allowed, with each two between them 5 MHz distant. This procedure is several minutes long, so it's convenient not to enable any node in this phase. Obviously, routing tables are dynamics, but for the particular mesh, memorization of all addresses can be avoided. In effect, it uses a sequential numeration: from 00:00 (exadecimal number) to maximum FF:FF. Number 00:00 is for MAC address of coordinator, whereas the progressive identification numbers are assigned to the other end devices.

In the case of mesh networks, the access mode CSMA/CA of the transceiver can be fulfilled by means of two different mechanisms: beacon and no-beacon. If no-beacon method has been used, all nodes can transmit only when state of channel is idle. An example is the MiWi protocol which uses no-beacon network. In the beacon method, node can transmit at pre-defined time ranges: the coordinator starts a beacon frame whose all nodes are synchronized. Normally, each node transmits and receives in its assigned time interval, inside the beacon frame.

OV7710 CMOS sensor shows a VGA default resolution, size of active image array of 640columns per 480 rows (307,200 pixels) and transfer rate of 30 frame per second. Output formats are: YCrCb/YUV 4:2:2, RGB raw, and finally 10 bits digital video. Since the microcontroller elaborates images data for detecting edges and contours, we choice RGB raw output format. Sensor converts light intensity (photons number) to proportional electrical charge. It is not sensible to light wavelength. So, filters (red, blue and green) must be placed before each pixel. The order of the matrix sequence defines the named Bayer matrix with 50% of green colour, 25% of red and 25% blue. Simple algorithms convert data from RGB raw to RGB and then to grey levels. The grey level format is introduced in order to apply edge detection algorithm [12, 13].

The control of output format and other controls as white balance and exposure time, can be realized by use of Serial Camera Control Bus (SCCB) and by configuring sensor registries from PIC32. Microcontroller communicates to optical sensor by means of two interfaces: the previous SCCB adopting I2C standard protocol and the first synchronous serial SPI interface for transmitting RGB raw data. The second serial SPI interface has been used for the communication with the transceiver.

In order to decrease energetic consumption some features are carried out. Specifically, a custom protocol is optimized to decrease re-mapping computational cost and latency. Moreover, by means of Clear Channel Assessment (CCA), MRF24J40MA transceiver can recognize if the channel is busy or idle. Three different modes are available for the recognition, respectively: if received energy exceeds a prefixed threshold, if there is a standard IEEE 802.15.4 signal without threshold constraints and finally if there is a standard IEEE 802.15.4 signal that exceeds a prefixed threshold. In particular, power intensity received is recorded into RSSI register. These modes allow one to adjust the power with which the transceiver is transmitting. By means of a Command Frame some test packets are sent together with request of an ACK message. Test packets are written on the records. Next they are compared with data of RSSI for usage of minimum transmission power. Finally, we have taken care of the management of sleep mode by means of essential temporization and duration of detection and elaboration activities. In effect, PIC32 microcontroller could absorb 300 mA of maximum electrical current intensity. Transceiver absorbs 23 mA if it transmits around to 100 meters, whereas absorption decreases to 2 μA in sleep mode. These absorption values are evaluates with 3.3 V voltage supply for all devices. The routers are always active. The coordinator can be deactivated if it manages a mesh and no end-device is connected to it. End-device; the device remains in sleep mode when not transmitting data and processes.

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Infectious diseases: surveillance, genetic modification and simulation

H. L. Koh[1], S. Y. Teh[2], D. L. DeAngelis[3,4] & J. Jiang[4]
[1]*Disaster Research Nexus, School of Civil Engineering, Universiti Sains Malaysia, Malaysia*
[2]*School of Mathematical Sciences, Universiti Sains Malaysia, Malaysia*
[3]*U.S. Geological Survey, Gainesville, Florida, USA*
[4]*Department of Biology, University of Miami, Florida, USA*

Abstract

Infectious diseases such as influenza and dengue have the potential of becoming a worldwide pandemic that may exert immense pressures on existing medical infrastructures. Careful surveillance of these diseases, supported by consistent model simulations, provides a means for tracking the disease evolution. The integrated surveillance and simulation program is essential in devising effective early warning systems and in implementing efficient emergency preparedness and control measures. This paper presents a summary of simulation analysis on influenza A (H1N1) 2009 in Malaysia. This simulation analysis provides insightful lessons regarding how disease surveillance and simulation should be performed in the future. This paper briefly discusses the controversy over the experimental field release of genetically modified (GM) Aedes aegypti mosquito in Malaysia. Model simulations indicate that the proposed release of GM mosquitoes is neither a viable nor a sustainable control strategy.
Keywords: dengue, A H1N1, GM mosquitoes, simulation.

1 Introduction

The World Health Organization (WHO) announced on 11 June 2009 that the influenza A (H1N1) has reached the stage known as pandemic alert phase 6 with moderate severity. On 10 August 2010, WHO declared that pandemic alert phase 6 for A (H1N1) is officially over and the world has entered into the post pandemic period. However, the looming threat of another A (H1N1) pandemic

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110221

remains. During the height of this A (H1N1) 2009 pandemic, there were concerns that more severe forms of A (H1N1) might emerge as second waves in the ensuing winter months. These second waves of disease might cause more people to be infected and might also induce higher fatality. This concern regarding the potential emergence of more potent second waves is premised upon the experience of the 1918-1919 Spanish Flu (A-H1N1), during which the second waves turned out to be more pervasive and destructive than the first [1]. Four decades later, two pandemics known as the Asian Flu (H2N2) of 1957-1958 and the Hong Kong Flu (H3N2) of 1968-69, resulted in deaths of about one million people. Having witnessed three pandemics in a span of a century, the last being forty years ago, the health care professionals have ample reasons to be alert to the potential of yet another pandemic of similar severity in the near future. At the height of the A (H1N1) epidemic in Malaysia in June 2009, the authors began to develop a flu simulation model known as FluSiM to track and understand the evolution of this epidemic. A simple model framework was chosen to reflect the degree of understanding of the A (H1N1) transmission dynamics, as well as to avoid the need for excessive medical data that were not available at that stage of disease development. The rational was to keep the model as simple as possible but not any simpler, consistent with the quality of data publicly available then (fig. 1). Further improvement is possible and indeed desirable in order to better utilize the predictive ability of the model. Figure 1 shows the number of new infected individuals on a weekly basis for the whole of Malaysia, beginning on week 24 and ending in week 50. The infection appeared to peak around week 33, about 60 days later. It is still not certain whether the cases reported on week 24 indeed started the subsequent infections. Hence, the time to peak might well be less than 60 days. A flu simulation model known as FluSiM is developed to fit the data for the A (H1N1) 2009 influenza for Malaysia. The bell shape curve of fig. 1 suggests that the popularly used model, based upon the concept of susceptible-infected-recovered (SIR), is appropriate and will be adopted in this paper.

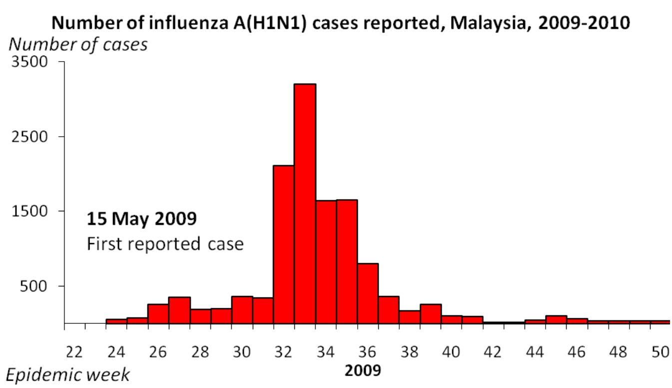

Figure 1: Weekly infected cases for Malaysia.

2 SIR model: FluSiM

FluSiM is an SIR model developed to investigate the transmission dynamics of flu between susceptible individuals and infected individuals [2–4]. An infected individual is considered as infective. Central to this model framework of an infective disease epidemic for a given population is the assumption that new infective persons are generated by the mixing of uninfected susceptible persons with existing infective persons. Most epidemic models typically assume that the rate of increase of new infective individuals is proportional to the product of the number of susceptible individuals (S) and the number of infective individuals (I), shown as (βPsi) in eqs. (1) and (2). This is a well known mass action assumption, which has been successfully applied to a wide range of human and wildlife infectious diseases. This assumption implies that each susceptible and each infective are at all times equally accessible and exposed to each other. This underlying assumption of uniformity of exposure is normally not fully satisfied. An infective recovers after T days ($T = 1/\alpha$), after which he is no longer infective and is removed from the Infective compartment (I) and moved to the Recovered compartment (R), as shown in the term ($-\alpha i$) in eqs. (2) and (3). Equations (1) to (3) constitute the SIR model with $s = S/P$, $i = I/P$, $r = R/P$ and P = total population. Here, S = number of Susceptibles, I = number of Infectives, R = number of Recovered and $P = S + I + R$.

$$\frac{ds}{dt} = -\beta Psi \qquad (1) \qquad\qquad \frac{di}{dt} = \beta Psi - \alpha i \qquad (2) \qquad\qquad \frac{dr}{dt} = \alpha i \qquad (3)$$

Early detection of epidemic of A (H1N1) requires real time data and real time simulation. Some variables are observable (e.g. infected persons I); some are hidden variables that are not observable (e.g. susceptible persons S). The mean duration of infectivity T is an important parameter that hopefully could be reliably compiled during the course of the epidemic. On the other hand, the dynamics of transmission of A (H1N1) from the infective to the susceptible is not well understood. Further, direct measurement of the disease transmission rate is not possible. This transmission rate (known as contact rate βP) can only be estimated by model calibration. However, large variability and uncertainty are inherent in these unobservable variables such as the contact rate βP and the total number of susceptible individuals P in the model population.

An important concept in infectious disease transmission is the basic reproductive number, usually denoted by R_0. The basic reproductive number R_0 is defined as the average number of new infections that one infected individual generates in the susceptible population during the time that infected individual is infective [5]. For the SIR model, $R_0 = \beta P/\alpha = \beta PT$. If R_0 is greater than 1, an epidemic will occur; if R_0 is less than 1, the outbreak will die down. A series of simulations was performed to test model sensitivity to input parameters α and βP, the results of which are plotted in fig. 2. The left figure shows the ratio I/P (the proportion of susceptible that are eventually infected), while the right figure depicts the time to disease peak, as functions of α and βP. Based upon fig.1, the

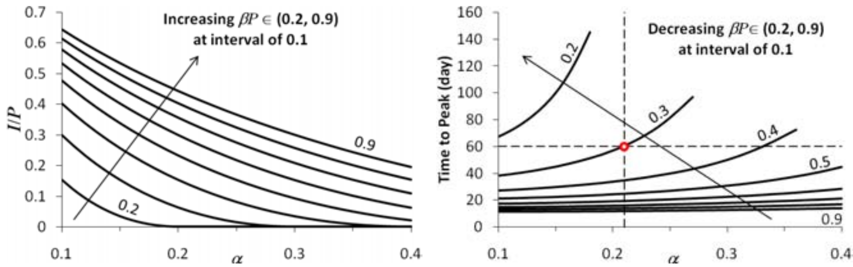

Figure 2: Dependency of FluSiM simulation results on α and βP.

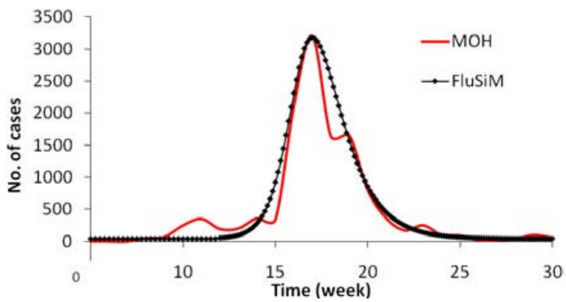

Figure 3: Comparison of MOH data and FluSiM, α = 0.21, βP = 0.3, R_0 = 1.4.

time to disease peak is about 60 days, which can be matched to various combinations of α and βP in fig. 2 (right). Based upon literature search, the infective period T for A (H1N1) varies generally between 3 to 7 days [4], or α between 0.1428 and 0.3333 d^{-1}. Given the status of medical care in Malaysia, an infective period of about 5 days or $\alpha = 0.2\ d^{-1}$ is appropriate. The time to peak of 60 days can be fitted to the choice of $\alpha = 0.21\ d^{-1}$ and $\beta P = 0.3$ with $R_0 = \beta PT$ = 1.4. The infection curve for this choice is shown in fig. 3, indicating reasonably good fit with MOH (Ministry of Health) data.

3 Future surveillance and simulation program

By fitting FluSiM model to A (H1N1) 2009 outbreak data for Malaysia, R_0 has been estimated to be around 1.4, which is comparable to the R_0 values of between 1.4 and 1.6 estimated by the SIR model for La Gloria in Mexico. This value is also comparable to the R_0 value of approximately 1.3 estimated for regular seasonal strain of influenza. For the 1918-1919 pandemic strain, R_0 has been estimated to be significantly higher, between 1.2 and 3.0 for community-based settling, and between 2.1 and 7.3 for confined settling [6]. The influenza A (H1N1) has been undergoing cross species evolution, and has been shown to have arisen from recombination of swine, avian and human strains. This continuous recombination may result in new strains, which may have high values of $R_{0,}$ accompanied by high fatality rate, which could potentially inflict devastating medical consequences. Hence, we must establish an integrated surveillance and simulation program that is capable of detecting the eminent emergence of influenza that has the potential of inflicting severe consequences because of the high reproductive number R_0, accompanied by high fatality rate. The fatality rate is intimately related to the viral activities and properties, which is a domain of virologists. It is imperative that virologists should have the ability to isolate and identify flu viruses that have the potential of high fatality. High reproductive number R_0 may result from a combination of factors, including viral properties, mixing pattern of human population and demography. In particular, the duration T of infectiveness of the disease plays an important role in determining the reproductive number since $R_0 = \beta PT$. The contact rate βP depends on both the transmission efficiency of the flu β and the total number of susceptible P in a given community. Estimating β and P requires real-time data and real-time model calibration, in addition to detailed surveillance of disease evolution. The accuracy of the SIR model is premised upon the uniformity of mixing between susceptible and infective individuals in the population. This uniformity may not be valid for large population living in big cities. Therefore, communities living in large cities such as Kuala Lumpur should be divided into sub-populations, to comply with the uniformity assumption, in order to improve the predictive capability of the SIR model.

4 Controversy over genetically modified mosquito

The Malaysia Institute of Medical Research (IMR), in collaboration with UK-based Biotech company Oxitec, has obtained approval from the Malaysian National Biosafety Board to conduct limited field trials of releasing genetically modified (GM) male mosquitoes (known as OX513A) to control the population of natural Aedes aegypti mosquitoes that carry the dengue virus. The GM male mosquitoes will mate with natural females to produce larvae that accumulate an extra enzyme to toxic levels, in the absence of the antibiotic tetracycline. This accumulated enzyme will eventually kill the larvae before they mature into adult mosquitoes, according to theory. These GM male mosquitoes will compete with natural male mosquitoes to mate with natural females. In theory, repeated releases of GM males would reduce natural mosquito population in dengue prone areas. However, the natural mosquito will grow back to their natural population level after the discontinuation of GM mosquito release. The mosquitoes will be released in the inland districts of Bentong in Pahang and Alor Gajah in Malacca, according to the National Biosafety Board. The release in each location will proceed in two phases: the first at a site at least half a kilometre from the nearest human settlement, and the second in an inhabited site. For each experimental release, an estimated 4000 to 6000 male GM mosquitoes are expected to be released, along with similar number of natural male A. aegypti mosquitoes. These experiments will be repeated over several months. Mosquitoes in the release sites will be captured using mosquito traps, and will be monitored for at least one month. At the end of the field trial, fogging in a 400 m radius is required. A second fogging should be conducted one week after the first fogging.

This planned controversial field experiments have aroused considerable anxiety among NGOs and concerned scientists, primarily due to the lack of transparency, the absence of meaningful and effective public participation, and the seeming haste in the approval process. Serious ethical, legal, public health and human rights issues involved in these experiments have not been sufficiently addressed by the Malaysian approval authorities. Lab tests had shown that three to four percent of the offspring of male GM mosquitoes mating with normal females do actually survive into adulthood, contrary to what has been falsely claimed that all GM larvae will die as intended. This residual mosquito will eventually grow in population size quickly due to their fast development rate. Further, female GM mosquitoes might accidentally be released. The males are separated from the female GM mosquitoes based on the size of the pupae. This separation process is not completely safe-proof. Because of the controversy, the IMR has yet to fix a new release date, having failed to initiate the field experiment as planned earlier. The IMR and Oxitec have cited the reported success of similar experiments conducted in the Cayman Island to justify their field experiment. The reported success in the Cayman Island should not be used to project success of similar experiment in Malaysia, as the geography of the two sites are vastly different. While Cayman Island (land area 200 km^2) is small and isolated from populations by the surrounding sea, Malaysia (land area 330,000 km^2) is a large country surrounded by many countries with huge populations. This geographical connectivity allows mosquito free range of movement over time, thereby permitting natural mosquito to invade areas previously rid of mosquito due to the GM experiment. This ability of natural mosquitoes to re-invade regions previously void of mosquitoes will be demonstrated in our simulations.

5 Simulation model for GM mosquito

This paper investigates by model simulations the efficacy of controlling natural Aedes aegypti mosquito population by the release of GM mosquitoes into the natural habitat. Esteva and Yang [7] proposed a mathematical model (4)-(9) to assess the effectiveness of controlling mosquitoes by the sterile insect technique. Their modelling approach is adapted in this paper to investigate the efficacy of releasing GM mosquito into a natural habitat to eradicate natural mosquito populations as a way to control mosquito-borne diseases. In this model, the life cycle of a mosquito is divided into two stages: the immature aquatic form (eggs, larvae and pupae) and the adult winged form [8, 9]. We denote by A the immature aquatic form of the mosquito. The adult wing mosquitoes are divided into five compartments. The first compartment consists of unmated single females, which is denoted by F_s. Some of these single unmated females remain unmated and therefore remain in F_s, while the remaining singles are mated. The mated females are further divided into two compartments. Those that are

Table 1: Parameter values used for simulation study [7, 10].

μ_A	μ_s	μ_f	μ_u	μ_M	μ_T
0.05	0.05	0.05	0.05	0.1	0.1
ϕ	γ	r	β	C	pq
5.0	0.075	0.5	1.0	600	0.7

fertilized are moved into compartment denoted by F_f, while the unfertilized females are moved to the compartment F_u. Natural male mosquitoes form members of the compartment denoted by M. Finally, the GM male mosquito is grouped into compartment denoted by M_T. This set of compartment notations will be used in this paper. For example, the per capita mortality rates of the immature aquatic form, unmated single females, mated fertilized females, mated unfertilized females, natural male and GM male mosquitoes are denoted by μ_A, μ_s, μ_f, μ_u, μ_M and μ_T, respectively. This GM simulation model will be run with input parameters shown in table 1. Details of the model can be referred to [7].

$$\frac{dA}{dt} = \phi\left(1 - \frac{A}{C}\right)F_f - \left(\gamma + \mu_A\right)A \tag{4}$$

$$\frac{dF_s}{dt} = r\gamma A - \frac{\beta M F_s}{M + M_T} - \frac{\beta_T M_T F_s}{M + M_T} - \mu_s F_s \tag{5}$$

$$\frac{dF_f}{dt} = \frac{\beta M F_s}{M + M_T} - \mu_f F_f \tag{6}$$

$$\frac{dF_u}{dt} = \frac{\beta_T M_T F_s}{M + M_T} - \mu_u F_u \tag{7}$$

$$\frac{dM}{dt} = \left(1 - r\right)\gamma A - \mu_M M \tag{8}$$

$$\frac{dM_T}{dt} = \alpha - \mu_T M_T \tag{9}$$

A = population of the aquatic forms of mosquito;
F_s = population of winged females before mating (singles);
F_f = population of mated fertilized winged females;
F_u = population of mated unfertilized winged females;
M = population of winged natural males mosquito;
M_T = population of winged transgenic GM males mosquito;
γ = development rate of aquatic form, day^{-1};
β = mating rate of natural mosquito, day^{-1};
α = number of winged transgenic males released per day, mosquito day^{-1};
ϕ = oviposition rate of fertilized winged females, day^{-1};
C = carrying capacity of aquatic forms of mosquito;
r = ratio of aquatic forms that becomes winged females, mosquito/mosquito;
$\beta_T = pq\beta$ = mating rate of transgenic mosquito, day^{-1};
p = ratio of transgenic males to natural females, mosquito/mosquito;
q = ratio of effective mating rate of transgenic males, day^{-1}/ day^{-1};
μ_A = mortality rate of aquatic forms, day^{-1};
μ_s = mortality rate of winged females before mating, day^{-1};
μ_f = mortality rate of mated fertilized winged females, day^{-1};
μ_u = mortality rate of mated unfertilized winged females, day^{-1};

μ_M = mortality rate of winged natural males, day^{-1};
μ_T = mortality rate of winged transgenic males, day^{-1}.

6 Simulation results for GM mosquito

The parameter values used in the simulation study are listed in table 1. We further assume that $\beta_T/\beta = p \times q = 0.7$, which implies that GM males lose 30% of the natural mating capacity due to imperfect physiological modifications following GM process and less than optimal choice of release site resulting in reduced mating success [7]. Additional details regarding *pq* will be discussed in a later section. To initiate mosquito population, we choose an initial population consisting of only aquatic form with density equivalent to 90% of carrying capacity of aquatic form (denoted by $A/C = 0.9$). This choice of initial population is appropriate as the GM release is conducted in areas infested with Aedes mosquito. It is not necessary to have initial population of adult mosquitoes, as the natural aquatic forms will mature into adult forms. Inclusion of initial adult forms into the model framework would not change any conclusions reached in this paper. A large initial population of GM male mosquitoes 20 times the carrying capacity of aquatic forms ($M_T/C = 20$) is assumed to be released into the experimental site at the start of the simulation. Other initial release conditions will also be simulated for sensitivity analysis. In section 6.1, we consider the case with completely *enclosed* release site, where mosquitoes will not be recruited from external sources. Then in section 6.2, we consider the case with *porous* release site, which is open to its neighbour, in which case mosquitoes will be recruited from external sources by natural diffusion and advection.

6.1 Completely enclosed release site

We first consider the case in which the release site is assumed to be completely isolated from its neighbours, with no possibility of mosquito recruits coming from external regions. Various scenarios are simulated. The first scenario considers a continuous release of GM male mosquitoes (equivalent to α = 75 mosquitoes/day) into this enclosed release site, in addition to the initial large one-time release of GM males ($M_T/C = 20$) mentioned earlier. The second scenario considers no continuous release of GM male mosquitoes (α = 0 mosquitoes/day) after the initial one-time release. Simulation results for these two scenarios are compared in fig. 4. The initial one-time release of GM male mosquitoes will quickly decrease the number of aquatic forms, as the offspring produced by the female mosquitoes that mated with GM male mosquitoes are killed during the aquatic phase before they can develop into mature form. Hence, the adult form will be decimated. However, without continuous release of GM male mosquitoes after the initial one-time release, the GM male mosquitoes released initially will eventually die. The residual mosquito population in the enclosed site will then recover to their normal population levels in the absence of GM males. It is assumed that both GM and natural males have the same mortality rates. On the other hand, if there is a continuous unending release of

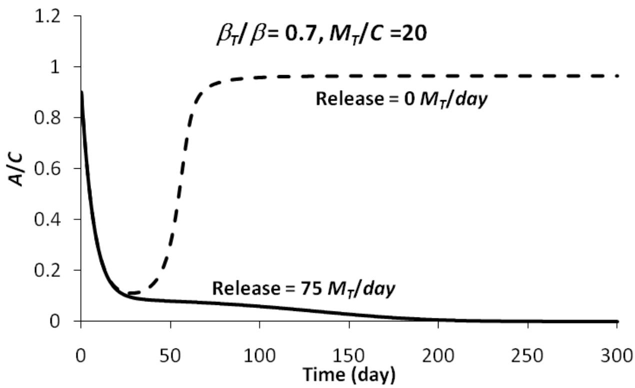

Figure 4: Proportion A/C subject to one initial release and continuous release of GM mosquitoes.

GM male mosquitoes, the natural mosquitoes will be wiped out eventually, at the indicated rates of initial and continuous release. We next consider reduced rates of initial release of GM males.

The third scenario considers several cases with reduced one-time initial release of GM mosquito equivalent to 1, 4, 10, 15 and 20 times the carrying capacity of aquatic forms (C), and with the same continuous release of 75 mosquitoes per day. This sensitivity analysis indicates that the natural mosquito population will initially decrease to lower levels due to the large initial one-time release of GM males. The higher the initial one-time release rate, the sharper will be the initial mosquito population depression. However, with the exception of release rate equivalent to 20 times C, the natural mosquito population will eventually grow back to their natural population level. Only the time taken to recover to the natural population level varies. The higher the initial one-time release rates, the longer will be the time taken to recover to the natural state (fig. 5). In short, the proposed GM mosquito release program is not a viable strategy to eradicate natural A. aegypti mosquitoes, as the natural mosquito population will persist in this enclosed release site.

Finally, we investigate the role of GM male mating success in reducing natural mosquito population. For this purpose, two critical parameters are relevant. First, the parameter p $(0 \le p \le 1)$ refers to the relative effectiveness of GM male mosquitoes in searching for female natural mosquitoes for mating. Values of p are sensitive to the environment into which the GM male mosquito is being released [11, 12]. The parameter p plays an important role in reproduction success of GM males in a habitat with varying contact rates with natural female mosquito. Next, the parameter q $(0 \le q \le 1)$ may be thought of as a measure of reduced efficiency in mating success due to physiological imperfection induced by the genetic modification process. Sensitivity analysis is performed to assess the combined impact of $\beta_T/\beta = pq$ on the persistence of the natural mosquito population subject to the release of GM males, the result of which is presented in fig. 6. For this purpose, we first assume a 16% reduction in mating success of

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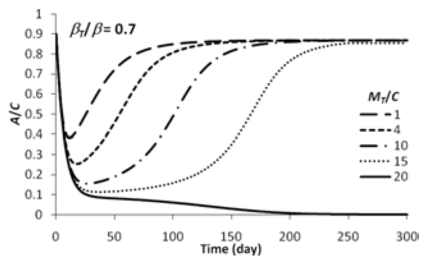

Figure 5: Proportion A/C for several M_T/C.

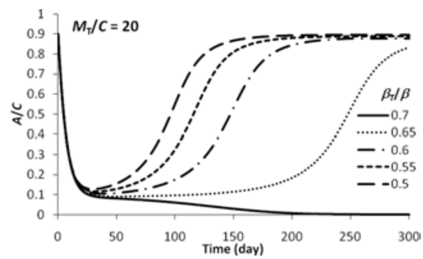

Figure 6: Proportion A/C for several β_T/β.

GM males due to imperfection of genetic modification. Further, we also assume a 16% reduction in the success of choosing the optimal release site. This choice results in $p \times q = 0.84 \times 0.84 = 0.70$. A large initial one-time GM release (M_T/C = 20) followed by a continuous daily release of GM males (equivalent to α = 75 mosquitoes/day) discussed earlier and subject to pq = 0.70 will wipe out the natural population eventually. However, reducing pq to 0.65 or lower will allow the natural population to eventually recover and persist in its natural population level even in the presence of GM mosquitoes. To perpetually maintain a value of $pq \geq 0.7$ remains a goal that is not viable to achieve under normal field conditions and subject to imperfect genetic modification. Hence, the strategy of releasing GM male mosquitoes to control natural A. aegypti population is not viable, based upon model simulations performed in this paper.

6.2 Porous release site

Physically connected to external areas, a natural release site is neither completely enclosed nor completely isolated from its neighbours. Hence, mosquitoes from external sources will be able to invade the release site over time. We therefore simulate the propagation of mosquito travelling wave in an extended natural habitat covering tens of kilometres. The wave is initiated by a small initial population equivalent to 1% of the carry capacity at the location X = 0 km. We assume that the mosquito disperse in space in search for meals and breeding grounds, assisted by natural atmospheric diffusion, which is modelled by a dispersion coefficient D of 0.013 km^2/d [8, 13]. In some situation, wind might also help to transport mosquito over space, which is modelled by an advection coefficient v of 0.1 km/d. Figure 7 (left) shows the symmetrical spread of mosquito in both directions from its small initial population at X = 0 km, given the values of D = 0.013 km^2/d and v = 0 km/d. The mosquito population advances symmetrically in both directions with travelling wave velocity λ of 0.3 km/d. Figure 7 (right) shows the asymmetrical spread of mosquito from its small initial population at X = 0 km, given the values of D = 0.013 km^2/d and v = 0.1 km/d. The mosquitoes propagate in the downwind direction with travelling wave of λ = 0.4 km/d and in the upwind direction with λ = 0.2 km/d. Based upon these simulation results, it may be concluded that mosquito might readily invade any

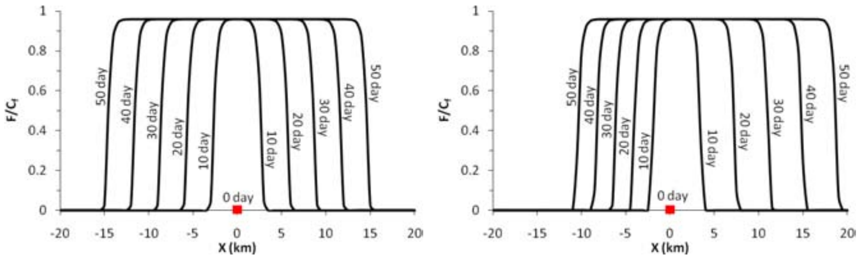

Figure 7: Mosquito traveling waves in a natural environment with no advection (left) and with advection towards the east (right).

habitat with travelling wave velocity of the order of λ = 0.1 km/d. A geographical separation of the order of one or two km provides inadequate resistance to mosquito invasion. Hence, the strategy of GM male release to control natural mosquito population is not sustainable in the long run.

7 Conclusion

The simple SIR model is suitable for the simulation of influenza A (H1N1) 2009 in Malaysia. To prepare for a scenario with very severe form of influenza in the future, an integrated surveillance and simulation program is essential. A large community living in big cities must be divided into sub-populations in this SIR model in order to improve predictive capability of the model. The planned release of the genetically modified male mosquitoes into natural habitat to control mosquito population has aroused considerable attention. Simulation results indicate that the release of GM male mosquitoes to control natural Aedes aegypti population is neither viable nor sustainable.

Acknowledgements

Financial support provided by Grants 1001/PMATHS/817024, 1001/PMATHS/817025, 1001/PMATHS/811093 and 203/PMATHS/671187 is gratefully acknowledged.

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Strategies for crowdsourcing for disaster situation information

E. T.-H. Chu[1], Y.-L. Chen[1], J. W. S. Liu[2] & J. K. Zao[3]
[1]*Department of Computer Science and Information Engineering, National Yunlin University of Science and Technology, Taiwan, R.O.C.*
[2]*Institute of Information Science, Academia Sinica, Taiwan, R.O.C.*
[3]*Department of Electronic and Computer Science, National Chiao Tung University, Taiwan, R.O.C.*

Abstract

When existing surveillance sensors used by a disaster warning and response system cannot provide adequate data for situation assessment purposes, crowdsourcing information collection can be an effective solution: People armed with wireless devices and social network services can be used as mobile human sensors. Their eye-witness reports can complement data from in-situ physical sensors and provide the system with more extensive and detailed sensor coverage. The crowdsourcing strategy used by the system can be random, relying solely on mobility of individuals for coverage of the threatened area; or crowd-driven, with the system providing situation updates as feedback to aid the crowd; or system-driven with individuals moving in response to directives from the system. The relative merits of the strategies clearly depend on the disaster scenario and the characteristics of the crowd.

This paper presents a general crowd model for characterizing individuals within a crowd and the crowd as a whole and an abstract mobility model of crowd movements in the threatened area. The models can be specialized to characterize different disaster scenarios and crowds, and used in the simulation of the crowdsourcing strategies for evaluation purposes. Data on relative performance of different strategies for two types of disasters were thus obtained.

Keywords: crowdsourcing, disaster management, crowd mobility model.

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110231

1 Introduction

A disaster surveillance and response system must estimate boundaries of threatened area(s), assess the threat potential and acquire situation awareness to support decisions on what alerts and warnings to issue when a disaster seems imminent and how to handle emergencies and calamities during and after the disaster. In-situ sensors and sensor networks and remote sensor systems used to collect data for this purpose may not always provide the system with sufficiently complete and detailed view of the threatened area. The area coverage of a sensor network (or networks) and density of sensors deployed are often limited by costs. This is the primary reason that Gulf of Mexico coast and Southern California region were not adequately monitored by surveillance cameras and other sensors during the 2010 BP oil spill and 2009 California wildfire disasters [1, 2]. Other reasons for inadequate surveillance sensor coverage include that some in-situ sensors may be damaged just when they are needed and thick clouds, vegetations, buildings, etc. can render remote sensors (e.g., surveillance satellites and unmanned aerial vehicles) ineffective. The resultant blind regions in sensor coverage can leave responders ill informed of imminent dangers to hundreds of people. This was what happened during Typhoon Morakat in 2009 in Taiwan [3].

A way to get fuller and more detailed coverage than what physical sensors can provide is crowdsourcing data collection. People using wireless devices and Web 2.0 services are in essence mobile human sensors. Their eye-witness reports of conditions at different locations can complement data from physical sensors to eliminate blind spots and mend fragmentation in sensor coverage.

This paper focuses on alternative strategies used by a disaster surveillance system to manage *crowdsourcing data collection* (*CDC*) *processes*. To keep our discussion concrete without loss of generality, we assume hereafter that the system triggers a CDC process by broadcasting a data collection request to a crowd. The process ends when the system has collected enough data to construct a sufficiently complete view of the threatened area. Possible strategies used by the system can be divided roughly into three types: random, crowd-driven and system-driven. One can say that a *random strategy* is a minimal strategy. After broadcasting a CDC request, the system does nothing other than collecting and processing reports from the crowd, relying solely on mobility of individuals for coverage of the threatened area. According to the *crowd-driven strategy*, the system updates the observed current conditions of the threatened area based on reports it has collected and processed and provides the information as feedback to the crowd. Otherwise, it lets the crowd guide themselves in their exploration efforts after broadcasting a request. According to a *system-driven strategy*, the system issues directive(s) to all individuals or a selected subset of the crowd who has responded to its initial CDC request. Each directive to targeted individuals guides them in their exploration. The directive is also a new request, leading to new responses from the crowd. The communication between the system and the crowd repeats until the system has a complete view of the threatened area and the CDC process ends.

We can measure the relative performance of the strategies along multiple dimensions, including the accuracy of the estimated threatened area boundary and resolution of the view of the area, response time of the CDC process (i.e., time required to obtain the estimate and view), the costs and rewards of each CDC process and so on. We will return to define and discuss the figures of merit of our choice. Regardless the figures of merit used, the relative performance of strategies clearly depends on the disaster scenario and the crowd characteristics.

This paper makes three contributions to studies on strategies for crowdsourcing sensor data collection. The first is a general crowd model for characterizing each individual within a crowd and the crowd as a whole. Rather than some qualitative attributes, our model characterizes each individual in the crowd quantitatively in terms of his/her contributions to the CDC process. The quantitative nature of our model resembles the concept of crowd quality for quantification of the quality of crowdsourced spatial data and software testing [4, 5]. The second is an abstract and formal mobility model of crowd movements. The mobility model is also quantitative. It complements existing human mobility models such as the ones described in [6, 7] that were developed to characterize movements of people in their normal daily lives. Our models are meant to be specialized to characterize different disaster scenarios and crowds and used in simulation of crowdsourcing strategies for evaluation purpose.

The third contribution of this paper is a general methodology for evaluating strategies for crowdsourcing sensor data collection. A search of Internet for crowdsourcing strategies usually returns numerous entries on the subject, too numerous to list as citations in this paper. None of them addresses effectiveness of strategies for managing CDC processes, however.

Following this introduction, Section 2 presents definitions and underlying assumptions. Section 3 present our models of the threatened area, crowd and crowd mobility and discusses how the models can be specialized to model different crowds (e.g., official responders, NGO volunteers, unknown crowds) and their mobility for different types of disasters (e.g., oil spill, earthquake, landslide, flood and wildfire) at different locales. Section 4 presents parameters of simulation experiments for the purposes of evaluating different system-crowd interaction and crowd mobility strategies. Section 5 defines figures of merits used to measure their performance and simulation data on two types of disasters as case studies. Section 6 summarizes the paper and presents future work.

2 Definitions and assumptions

Clearly, the quality of the human sensor data collected by a CDC process and response time of the process critically depends on crowd quality [4]. According to their skills and motivation, we divide all participants of a CDC process roughly into types I, M and U.

(A) Participant Types

Participants of I-type are *ideal human sensors*. A *type-I individual* may have been trained or have practiced to be a human sensor. At each step during a CDC process, he/she moves to the right location promptly, makes a right observation and sends an accurate report. Ideal human sensors are likely to be government disaster responders (e.g., policemen, firemen, and soldiers) and some volunteered responders from NGOs (e.g., Red Cross), local communities, etc.

An *M-type participant* is highly motivated and hence, is reasonably responsive: he/she may be a registered volunteer, a person affected by the disaster, and so on. The participant is known to the system and can be rewarded in someway afterwards. However, the sensor data collected and reported by him/her may not be accurate.

U-type participants are unknown to the system. A U-type individual may take a longer time to respond to request or not respond at all. Moreover, the data collected by him/her may not be accurate. Nevertheless, past experiences have shown that unknown crowds can help in many ways during major disasters.

(B) Sub-strategies

A strategy for managing CDC processes can be divided into three parts. They are sub-strategies for participant selection, result quality assurance and system-crowd interaction. We present here an overview of the participant selection part. To do so, we note that in general, a strategy for managing CDC processes needs to take into account of not only crowd composition but also the fact that sensor data on some regions of the threatened area may be more critical than data on other regions. Take the Gulf Coast during the BP oil spill as an example. We are more concerned with protecting regions that are frequented by tourists and/or have rich varieties of vegetations and wildlife. It makes good sense to direct high quality participants to check those regions for tar balls and other early signs of oil than other parts of the coast. This aspect of sensor coverage can be accounted for by giving an *importance value* v_i (or simply *value*) to each region in the threatened area: The more critical the region, the higher its value.

The problems solved by a *participant selection* (*crowd composition*) *strategy* include how to make best use of the available high quality participants to achieve specified goals subject to various constraints. To illustrate, we consider the simple case where the system uses only type-I participants to explore a threatened area that has n regions with values v_i, for i = 1, 2, …, n. Suppose that the goal of a budget constrained CDC process is to maximize the total value of all the explored regions in the threatened area, under the condition that each region is to be fully explored or not explored at all. Then, the problem P_1 to be solved by the participant selection sub-strategy can be stated as follow:

$$P_1 : \quad \textit{Maximize} \quad \sum x_i v_i \tag{1}$$

$$\textit{Subject} \quad \text{to} \quad \sum x_i c_i \leq B, \tag{2}$$

$$x_i \in \{1,0\}, \quad i = 1 \cdots n,$$

In (1) and (2), B is the total budget available for each CDC process, c_i is the cost of sending a sufficient number of responders to collect data for region i, and variable x_i is 1 if the region is to be explored and is 0 otherwise.

The integer programming problem P_1 assumes that the total number of type-I participants and the response time of the CDC process are unconstrained. In general, these constraints also need to be considered. For major disasters such as BP oil spill and southern California fire [1, 2], the system also needs to use

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registered but untrained type-M individuals and even unknown participants. We can formulate the constrained optimization problem of allocating I type and M type participants to regions similarly. Due to space limitation, we leave the problems of participant selection to a future paper [8].

Hereafter, we focus on sub-strategies for *result quality assurance* and *system-crowd interactions*. The former is concerned with ways to process sensor data reported by participants, which we will discuss shortly. The latter governs system-crowd interactions. Alternatives include random, crowd-driven and system-driven strategies defined earlier in Section 1. For studying their relative performance, we assume that the numbers of types I and M individuals participating in a CDC process are known and fixed during each CDC process and denote the numbers by N_I and N_M, respectively. The number N_U of type-U individuals is unknown and may vary during the process. Finally, we assume that all regions have the same value except for where it is stated otherwise.

3 Scenario, crowd and crowd mobility models

As it will become evident shortly, specifics about the characteristics of sensors are unimportant. To characterize the threatened area, we can start from the ideal condition. Ideally, the threatened area would be covered by a sufficient number of physical sensors at locations chosen to achieve the required spatial resolution. In other words, data provided by all the sensors would enable the system to generate a complete view of the area, including a sufficiently accurate estimate of the area boundary and fine spatial resolution.

Unfortunately, for reasons including the ones stated in Section 1, σ sensors S_1, S_2 ,…, S_σ are missing or broken. We assume here that the system knows their identities and locations. The goal of the CDC process is to acquire one or more eye-witness reports on the condition around the neighborhood of each missing sensor to complement data from existing physical sensors. Hereafter, we refer to such reports from participants as s*ensor samples* and *sample values*.

(A) Graph Model of Threatened Area

For the sake of managing CDC processes, it suffices for the system to characterize the threatened area by a directed graph containing σ nodes. Each node S_i in the graph represents a neighborhood of a specified size around a missing sensor S_i. There is a directed edge (S_i, S_j) from S_i to S_j if there are one or more paths along which participants can reach S_j directly from S_i. The label $T_{i,j}$ of the directed edge (S_i, S_j) is the minimal time required to go from S_i to S_j and upon arrival at the neighborhood of S_j, make an observation and send a sensor sample.

As an illustrative example, Figure 1(a) shows a part of a coastline threatened by oil pollution. The part should be under the watch of surveillance cameras and other physical sensors (e.g., for water quality) but is not. In the figure, the dots along the coastline mark the ideal locations of missing surveillance sensors. Human sensors, like physical sensors, at those locations can provide the system with needed data for complete coverage. Figure 1(b) shows the graph characterizing the scenario. In this case, the time to travel between two adjacent sensor locations is independent of direction of travel. We can simplify the graph by making it undirected and give each edge one label.

Figure 2 gives another example. The dots labelled S_i for i = 1, 2,…, 7 in part (a) of the figure mark where in a national park an early wildfire warning system should have sensors but does not. When there is a fire within a striking distance away, some combinations of low humidity, high temperature and wind direction and speed around those locations call for the evacuation of park visitors near by. Part (b) shows the graph maintained by the system for this scenario. In this case, the travel time between two sensor locations may depend on the direction of the travel, and not all sensor locations are connected by direct paths.

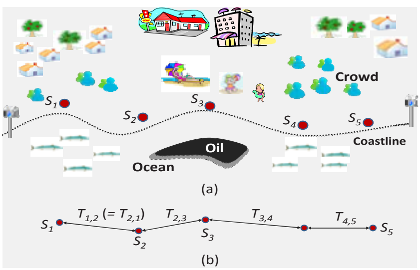

Figure 1: Oil spill disaster scenario.

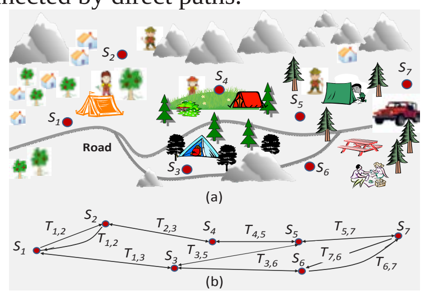

Figure 2: Wildfire surveillance scenario.

(B) Participant and Crowd Model

Similar to numerous details about disaster scenarios, many attributes of individual participants are unimportant for the purpose of managing CDC processes. Neither is what accurate sensor sample values are. The system can character each participant *k* abstractly by the following two sets of parameters.

Sample Errors The first set specifies the accuracy of sensor samples reported by the participant: Let η denote the number of sample values that participant k is to report at every sensor location.

$$\boldsymbol{\Theta}_k = (\Theta_{k,1}, \Theta_{k,2},\ldots, \Theta_{k,\eta}) \qquad (3)$$

is the *error* in each sensor sample. The error $\Theta_{k,i}$ in the i-th sample value is a random value with distribution function $F_{k,i}(x)$ (i.e., the probability that $\Theta_{k,i}$ is less or equal to x). Take the scenario illustrated by Figure 2 as an example. Participant k is requested to report temperature, humidity, wind direction and speed at each sensor location. In this case, each sensor sample contains four sample values. Errors in the values have different distribution functions.

Throughout this paper, we assume that these random variables are statistically independent. We also ignore the effects of such factors as technical problems, mob behavior, etc. and assume that sample errors of different participants are statistically independent. In case studies presented in subsequent sections, we do not further divide participants beyond types I, M and U. So, sample errors of participants of the same type are identically distributed. With a slight abuse of the notations, we index the distribution functions of these random variables by participant type and write them as $F_{I,i}(x)$, $F_{M,i}(x)$ and $F_{U,i}(x)$ (for $i = 1, 2, \ldots, \eta$) for types I, M, and U participants, respectively. Again, sample values reported by I-type participants are accurate (i.e., $F_{I,i}(x) = 1,\ x \geqq 0$, for all i).

How the system uses sample values reported by multiple participants of other types to improve result qualities depends on the types of sample values. For numerical sample values, the system can take average of sample values returned by the participants, knowing that the variance of error in the average decreases with the number m of reported values. For sample values that assumes binary values (e.g., presence of tar ball(s) detected or not detected), the system can also take average of the reported values. This is just a way of voting, with an average larger than 0.5 indicating that major participants reported TRUE or 1. An alternative is to take maximum (or minimum) of all sample values. For the oil spill scenario, this means that the system would take action to investigate as soon as some participant detected some sign of oil.

Response time The second set of parameters Δ_k and Π_k give the *response time per sample* of participant k:

$$R_k(i, j) = \Delta_k + \Pi_k T_{i,j} \tag{4}$$

Specifically, $R_k(i, j)$ is the amount of time required by the participant k to travel from location S_i to S_j and take and report a sample of S_j upon arrival at neighborhood of S_j. Δ_k is the *delay per sensor*: Upon receiving a CDC request, or after reporting a sample at a location, the participant may not move on to the next destination location immediately. This random variable accounts for this delay. Here, we assume that the distribution function $G_k(t)$ of Δ_k is not a function of sensor location. A more detailed model may use different distribution functions for different locations and different steps during a CDC process.

The *efficiency factor* Π_k in (4) accounts for the extra time above the minimal time per sample taken by participant k. It is a random variable of value equal to or larger than 1. Its distribution function $H_k(x)$ is identically equal to zero for $x < 0$. Similar to errors in sample values, delays per sample and efficiency factors of participants of each type are statistically independent, identically distributed.
In addition to being accurate, Type-I participants are also prompt. For them, $\Delta_k = 0$, and $\Pi_k = 1$. We use $G_M(t)$, $G_U(t)$, $H_M(x)$, and $H_U(x)$ to denote the distribution functions Δ_k and Π_k, respectively, for types M and U participants. These distribution functions, together with distribution functions of sample errors and the numbers N_I, N_M, and N_U of participants of types I, M and U, respectively, completely characterize the composition of the crowd.

(C) Mobility Models

A mobility model characterizes the movement of a participant from sensor location to sensor location during a CDC process in conformance the system-crowd interaction strategy used by the system. Possible models include the ones listed below. With the exception of the shortest-time-tour (STT model), the models assume that every participant, regardless of his/her type, plans one move at a time without looking ahead. The descriptions of the models below are in terms of the graph model of the threatened area: We say that a participant is at node S_i when we mean that he/she is in the neighborhood around the location represented by the node. By that the participant has visited node S_i, we mean that he/she has already taken and reported one or more sensor sample at that location. We say that he/she chooses an outgoing edge of S_i when we mean that he/she chooses to go next to the location represented by the sink node of the edge. As stated earlier, types I and M individuals who responded to the CDC request at the start a CDC process remain to be participants until the CDC process terminates. In contrast, at any step of the process, a type U individual may drop out with probability $D > 0$. The statements below are conditioned on that the participant at S_i does not drop out after visiting the node.

- *Random Walk* (*RM*) *Model*: After visiting $S_{i,}$ the participant is equally likely to choose any of the outgoing edges of S_i.
- *Random Walk Forward-Only* (*RMFO*) *Model:* The participant first discard from consideration all outgoing edges of S_i leading to sink nodes he/she has already visited and then chooses one edge among the remaining outgoing edges with equal probability.
- *Random-Least-Visited-Firs*t (*RLVF*) *Model*: The participant first marks the outgoing edges leading to sink nodes that have been visited fewest times by all participants and then with equal probability chooses an edge from the marked edges.
- *Global-Least-Visited-First (GLVF) Model:* The participant chooses with equal probability an outgoing edge among the outgoing edges in path(s) to the node (or nodes) that have been visited the least number of times among all nodes in the graph.
- *Shortest Time Tour* (*STT*) *Model*: The model assumes global knowledge of the graph model of the threatened area. Each participant follows a tour computed for him/her so that every node is visited by a specified number of participants in the shortest time.

RM and RMFO models are the only mobility models that are applicable when the system uses the random system-crowd interaction strategy. Again, RM is a pure random walk model. Take the scenario in Figure 1 as an example. A participant who is at S_2 when a CDC process starts is equally like to go left and right, back and forth until the system terminates the process. He/she is likely to have visited all the nodes if the process runs a sufficiently long time. A shortcoming is that he/she is also likely to visit some nodes (e.g., S_2, S_3 and S_4 in this example) many more times than other nodes.

Now, suppose that the participant chooses each move according the RMFO model and chooses S_3 from S_2. From S_3, the only choice is S_4, and at S_4 the only choice is S_5. At S_5 he/she has no node to visit and hence essentially drop out of the process. It is easy to see that unless the graph for the threatened area is nearly fully connected, participants should not follow this movement model.

The RLVF and GLVF models are applicable when the system uses the crowd-driven strategy and provides participants with the current numbers of visits of all the nodes. They appear to be better alternatives than RM and RMFO models. According to RLVF model, preference is given to adjacent nodes that have been visited the least number of times at the time. The model still has the common shortcoming of all mobility models which do not make use global information on connectivity of the sensor locations. GLVF model is a possible remedy, but each participant must consider all nodes for every move.

The STT model assumes that the CDC process is system directed. After receiving responses to its CDC request, the system computes for each responded participant a tour through the threatened area such that all sensor locations are explored by a specified number of participants in the shortest time. We note that if there is only one participant, the tour sought by the system is a solution of the well-known travelling salesman problem, which is known to be NP-hard. Given multiple participants, each of them only needs to visit nodes in a sub-graph. We want the maximum of the minimum lengths of their tours to be as short as possible. We need efficient heuristics to solve this variant of the travelling salesman problem and will present the heuristics in [8].

4 Experiment setup

To determine the relative performance of different system-crowd interaction and crowd movement strategies, we conducted several simulation experiments based on two disaster scenarios: oil spill disaster and wildfire surveillance. For the oil spill disaster, we used Figure 1(b) to represent the threatened area but added two nodes to represent two more ideal locations for missing surveillance sensors along the coastline. In total, we have seven locations. From left to right, they are S_1, S_2, …, and S_7. Any two adjacent locations are connected. In the wildfire surveillance scenario, we used Figure 2(b) to represent the threatened area. To keep the number of parameters small, we experimented with only the case where the distances between all adjacent locations are equal.

In both scenarios, a CDC request is broadcast to start a process of collecting sensor readings at all locations. The data reported in the next section were obtained from an experiment where the system uses different strategies to interact with different types of participants: Specifically, it uses the crowd-driven strategy to interact with types I and M participants and provides them with feedback so that they can move according to the Random-Least-Visited-First (RLVF) model. The system uses random strategy in its interaction with unknown crowd. Without feedback and guidance, type-U participants have no choice but to move according to the Random-Walk (RW) model. Regardless of his/her type, each participant moves to an adjacent location based on his/her mobility model after reporting a sample at each location.

To simplify our experiments, the number η of sample value taken at every location was set to one. A node is considered *visited* (and is marked as such) when a sufficiently accurate estimate of the sensor value for the location represented by the node has been obtained. By definition of type I, a node (location) is marked as visited immediately after a type-I participant has visited the node. For types M and U participants, we used *sample mean* (i.e., the average of sample values reported by these types of participants) at a location as a *sensor value estimate* (i.e., an estimate of the accurate sensor reading) for that location. The node is marked visited as soon as the standard deviation of the sample values reported by all types M and U participants who have visited the node become equal to or less than a specified threshold percentage of the estimate. We refer to this threshold as the *acceptance threshold*. The CDC process stops when all locations are marked as visited.

Parameters of the simulation experiments include distribution functions of error in sample value, delay per sensor and efficiency factor for types M and U participants. The data presented in Section 5 were taken in an experiment where the sample value reported by each type-M participant was randomly generated in the range [5, 45] with uniform distribution, and the sample value reported by each type-U participant was randomly generated in the range [0, 50] with uniform distribution. In other words, sample errors are uniformly distributed in ranges [-20, 20] and [-25, 25], for type-M and type-U participants, respectively. The acceptance threshold was set to 15%.

We set the minimum time per sample (i.e., the values of all edge labels) taken by a participant to 10 for all experiments. The efficiency factor of a type-I participant is 1, by definition. The efficiency factor of a type-M participant is randomly generated in [1, 2] with uniform distribution and of a type-U participant is randomly generated in [1, 10] with uniform distribution. For simplicity, we set to zero the delay per sensor for all participants and the drop-out probability of type-U participants. Finally, to remove the effect of initial locations of participants, we let all participants start at location S_4.

5 Performance measures and simulation results

We compare different strategies along two dimensions. The first is the *response time of the CDC process:* it is the length of time between when the system issues a CDC request to the instant when all nodes are marked visited.

The second performance measure is the spatial resolution of sensor coverage achieved by the process. To define this performance measure, let h denote the required time for a type-I participant to visit all locations: The s*patial resolution* achieved by a strategy is defined as the ratio of the number of visited locations in the duration h to the number of total locations. The higher the spatial resolution is, the better the strategy is along this dimension.

Figure 3 and Figure 4 show spatial resolution as a function of the number of participants. The data were taken in an experiment series in which there was only one type of participants for each experiment. As the figures show, the more type-M participants take part during a CDC process, the better the spatial resolution. In particular, Figure 3 shows that the spatial resolution becomes 100% when there are three or more type-M participants. In other words, in this oil spill disaster scenario, it is not necessary to use any trained type-I participant to patrol the area when there are more than three type-M participants. In contrast, type-U participants are not always helpful. As we can see from Figure 4, the spatial resolution does not improve noticeably when the number of type-U participants increases from three to six.

Figure 5 and Figure 6 show the dependency of the response time of the CDC process on the number of participants. Again, in each experiment, there is only one type of participants. We can see that in general, the more participants are involved, the shorter the response time is. When the number of participants becomes large, the difference among crowds becomes small. As Figure 5 shows, the response time of six type-M participants is almost the same as that of six type-I participants. In addition, both Figure 5 and Figure 6 show that when all participants are of type I, the response time of the CDC process does not improve much when the number of participants increases from two to six. Our results also indicate that participants following RLVF model perform much better than the ones following the RM model. For example, in Figure 6, the response time of a type-U participant is almost five times longer than that of a type-M participant.

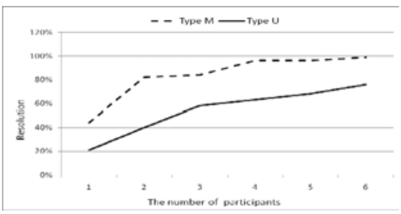

Figure 3: Oil spill disaster scenario.

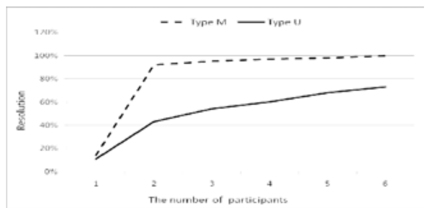

Figure 4: Wildfire surveillance scenario.

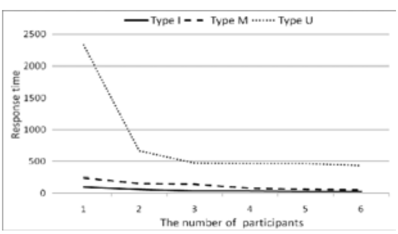

Figure 5: Oil spill disaster scenario.

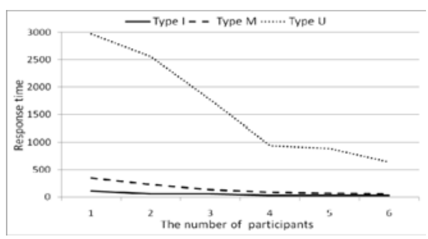

Figure 6: Wildfire surveillance scenario.

To further investigate the effect of crowd composition, we mix different types of participants in an experiment: Each crowd includes six participants. The response times for different crowd models are listed in Table 1. The 3-tuples in the first row of the table represent crowd models. Numbers in the 3-tuples gives the numbers of types I, M and U participants in the crowd, respectively. We can see that a crowd with type-I participants solely invariably achieves a short response time. Moreover, a crowd without type-I participants always performs worse than a crowd with type-I participants. The response time achieved by a crowd without type-I participants depends on the number of type-M participant As an example, in the wildfire surveillance scenario, the response time of crowd (0, 3, 3) is about 1.39 times longer than that of crowd (0, 6, 0).

Table 1: Response time of different crowd model.

	(6, 0, 0)	(3, 3, 0)	(2, 2, 2)	(3, 0, 3)	(0, 6, 0)	(0, 3, 3)	(0, 0, 6)
Oil spill disaster	30	42	49	54	56	220	431
Wildfire surveillance	30	37	49	52	61	85	642

6 Summary and future work

Previous sections presented general models that can be used to represent different disaster scenarios and characterize individual participants in a crowd and their movements in the threatened area for the purpose of studying strategies for crowdsourcing sensor data. The models abstract away irrelevant details about the disaster scene, in-situ physical sensors, individual participants and their movements so that we can focus on the characteristics of elements that are important for managing crowdsourcing sensor data collection.

The preliminary data presented above show that in general, the more participants are involved in a CDC process, the shorter the response time of the process and a crowd of type-I participants only usually has a short response time. As stated earlier, the response time may not improve noticeably when the number of type-I participants increases beyond some value, however. This fact indicates a need for effective methods to properly allocate trained responders for data collection function. Developing such methods is a part of our future work. For a crowd without type-I participants, our simulation results show that the number of type-M participant can have a significantly impact on the response time. On the other hand, type-U participants are not always helpful.

We made many simplifying assumption in studies done thus far. Most important ones are that the random variables characterizing relevant attributes of participants and sample errors are statistically independent. This assumption is clearly not always valid and will be removed in our future studies. As stated earlier, we leave problems that are theoretical in nature to a technical report [8] on theoretical foundation of the CDC process management.

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Application of Google Earth for flood disaster monitoring in 3D-GIS

M. Mori & Y. L. Chan
Department of Information and Computer Science,
Kinki University, Japan

Abstract

A prototype flood monitoring system has been developed using Google Earth related to Geographic Information Systems (GIS). GIS have become effective tools for analyzing flood disasters, especially for three-dimensional (3D) analysis. However, high performance commercial GIS are very expensive so many offices, such as the U.S. National Weather Service (NWS), use web-based flood monitoring systems such as Google Earth. A web-based monitoring system is a low cost and efficient means to monitor local occurrences of floods. The present monitoring system is designed to provide the output result via a web-based interface to agencies, in both the public and private sectors. The present system provides estimated inundation zones, water depth, and flood hazard map via a web-based interface, which are based on a two-meter Digital Surface Model (DSM). A 2 m DSM is a more precise 3D model when compared with the previous Digital Elevation Models (DEM).

Keywords: flood, Google Earth, 3D GIS, DEM/DSM.

1 Introduction

Flood damage is quite severe in northern Kyushu, Japan, during the yearly typhoon season. Floods are most frequent, making up 46% of all natural disasters and cause most human loss, affecting 78% of the population who have experienced natural disasters [1].

A prototype web-based flood monitoring system has been developed, which uses Google Earth pro v.5. Google Earth pro is more advanced than the standard version, which enables easy connection with not only Key-hole Markup Language (KML) files but also GIS files.

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110241

Google Earth pro allows high-resolution imagery to be combined with varied types of information, including GIS data. The most important input data is elevation data for the present flood monitoring system [2].

The present flood monitoring system is designed to meet the needs of agencies, in both the public and private sectors, and local governments are especially important for predicting and monitoring flood occurrences in their jurisdiction. However, GIS software such as ArcGIS may not be available to local governments, in which case KML files are quite useful for monitoring the output result using a Google Earth viewer.

For this research report, ArcGIS 9.3 (ESRI) and Google Earth pro v.5 are mainly used as a GIS analysis system and a viewer for PC Windows.

2 Flood monitoring system

2.1 Digital Elevation Model and input data

Several GIS data, such as static geospatial data, are necessary for flood monitoring systems. Digital Elevation Models (DEM) are quite important in generating a three-dimensional topographic map to enable flood risk assessment of damages. 3D GIS require DEM for analysis, which can construct a surface model around flood disasters. So far, a 50 m-meshed DEM developed by the Geological Survey of Japan (GSJ) is widely used for various GIS applications such as constructing 3D systems to create three-dimensional representations of the land in Japan. However the 50 m DEM is insufficiently accurate, making a higher-resolution DEM necessary. Then a 2 meter Digital Surface Model (DSM) was used for generating contour lines in the present system. A commercial company has recently developed a high-resolution DSM of up to 2 meter horizontal resolution meshed. A 2 m DSM is quite effective for various applications with GIS, having enough resolution to distinguish individual houses.

Also several digital maps such as ward boundary line data and road line data based on a 1:2500 digital topographic map from the Geographical Survey Institute (GSI) of Japan are used for data integration. The Google Earth viewer shows natural images of the geode, which do not include city boundary lines. Ward boundary lines are quite important to local governments when issuing flood alerts to the residents.

Rainfall rates and accumulations are available in 17 km squares by Automated Meteorological Data Acquisition System (AMeDAS) used by the Japan Meteorological Agency, which are updated every 10 minutes. Aerial photography with high spatial resolution of 0.25–0.5 m is used instead of low-resolution Google Earth images due to the granularity of the images in some regions.

2.2 Processing GIS data

The coordinates used in Google Earth are only approximate because it is merely a viewing tool for obtaining a general idea of the cache location rather than for technical application such as ArcGIS, and the errors in position can be as much as 30m. Thus it is necessary to correct the coordinates. The difference around the Onga River, the study area is found to be 14.64 m. Before processing GIS data, it must all be corrected to the Google Earth coordinates.

After geometric correction, precise contour lines are necessary for generating a 3-dimensional model of the region by 2 m DSM using 3D analysis in ArcGIS. A KML file for Google Earth is created by ArcGIS or Google SketchUP from GIS data.

2.3 Output results

One output result of the present monitoring system is inundation zone maps, which are estimated from 2 m DSM depending on rainfall rates and accumulations. Inundation zone images are shown with color-graded danger levels. Figure 1 shows a sample Google Earth image around the Onga River in northern Kyushu, Japan, and Figure 2 shows an estimated inundation zone of Figure 1 overlaid with a Google Earth image. Heavy rainfall occurred in northern Kyushu on July 19, 2003 [3]. As a result of the storms, the Onga River burst its banks, and the flood waters reached the central part of Iizuka City.

Figure 1: Google Earth image around the Onga River.

Also, the water depth of the river is calculated from the 2 m DSM and a topographic map to estimate the water flow in the river. Figure 3 shows a sample of the same region of the river in Fig. 2 overlaid with a Google Earth image.

Ward area maps in Iizuka City in northern Kyushu are shown in Fig. 4 overlaid with Google Earth images. Ward area maps are important for flood alerts.

Figure 5 shows a 3D view of a small hill overlaid with a Google Earth image, the 3D model of which is based on a 2 m DSM [4, 5].

Figure 2: Estimated inundation zone of the Onga River.

Figure 3: Water depth of the Onga River.

Figure 4: Ward area maps in Iizuka City, with additional information available by clicking.

Figure 5: 3D view of a small hill with contour lines.

3 Data delivery system

The present monitoring system is designed to provide the output result via a web-based interface to agencies, in both the public and private sectors. The type of output data are various, including GIS files (shapefile), KML files, and images. KML formatted files are most useful since they are used in the Google Earth viewer to display results without the need for any GIS software, and are a quite low-cost system.

Advanced users of GIS software such as ArcGIS by ESRI can use shape files to monitor results, and can also analyze them according to their technology and purpose. Shape files are available via ftp.

4 Conclusions

A prototype web-based flood monitoring system has been developed using 2 m DSM, which is designed to provide the output result. The most useful output result may be a KML file for Google Earth viewer. However, the present flood monitoring system does not include a physics-based hydrological model due to the simple system requirements. A physics-based hydrological model needs more precise rainfall rates and accumulations. The next model of the present system being considered is to include a physics-based hydrological model.

The update rate of data delivery is quite important for practical uses, especially in the public sectors for issuing sudden flash flood alerts. The output data of the present system is not updated periodically because it cannot automatically process data from AMeDAS.

Acknowledgement

The present work was partially supported by the Grant-in-Aid for Scientific Research (C) No.16510141 of the Ministry of Education, Science and Culture of Japan.

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Section 5
Socio-economic issues

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Post disaster reconstruction activities: a case study in Ghana

K. Adu-Boateng & B. M. Oppong
Community Based Rural Development Project (CBRDP), Ghana

Abstract

Ghana experienced heavy rains between August and September, 2007. In addition to the heavy rains experienced in the country, the Government of Burkina Faso also opened the Bagre dam in that country. Some parts of the three Northern regions (Upper West, Upper East and Northern) were affected by flash floods. The World Bank focused mainly on the reconstruction of public infrastructure and capacity building of relevant stakeholders that were involved in the reconstruction activities through the Northern Floods Reconstruction Programme (NFRP) under the Community Based Rural Development Project (CBRDP), funded by the World Bank and Agence Francaise De Development (AFD). The amount involved in the programme was $6,500,000.00 from the World Bank-IDA and $ 1,300,000.00 from the International Fund for Agriculture Development (IFAD) through the Northern Region Poverty Reduction Programme (NORPREP). However, the overall cost of public infrastructure was estimated at $125,000,000.00. The overall management of the programme was done by the World Bank.

The paper seeks to present the key features of the programme in terms of design, strategy, implementation and monitoring. It attempts to address how: (i) Local Government structures in Ghana's decentralization system were used in the implementation of the programme; (ii) an empirical formula developed to allocate the limited funds for the reconstruction activities; (iii) effective procurement methods employed without violating the World Bank and Ghana Government procurement procedures; (iv) the use and involvement of existing Institutions; and (v) the use of Rapid Result Approach (RRA) (where damaged infrastructure were reconstructed within 100 days).
Keywords: post disaster, public infrastructure, reconstruction activities, local government structures, procurement methods, rapid results approach.

doi:10.2495/DMAN110251

1 Introduction

The August, 2007 flash floods in Ghana, affecting in particular the three northern regions, caused a humanitarian situation, the scale of which the country has not experienced in many years, if ever.

The existing Government mechanisms, the resilience of the people and the tradition of the extended family system, contributed to limit the ill-effects of large displacement to people caused by the floods. However, the damage to crops, assets and livelihood, together with the environmental effects of stagnant and receding water provided the ingredients for a potential disaster for a population that is already vulnerable, placed them even further at risk.

According to the Assessment report of 2007, initial figures indicated that 260,000 people living in the three northern regions of the country were affected. In all 29 Administrative Districts were affected by the floods. Even though these figures, as in most emergencies are crude and preliminary, the immediate needs were obvious; food, access to safe drinking water and mosquito nets. Also, there was still a need for shelter in specific areas where people were staying out in the open air or in public buildings. Medium and longer term needs included restoration of livelihood and rehabilitation of infrastructure to promote commercial activities and access to areas cut off by the floods. The livelihood issue is a combination of crops and food stocks lost in the flooding, as well as the drought experienced earlier this year. Additionally, there was a continuous erosion of household assets with a negative spiral of debt as indicated by the field assessment after the floods.

In order to address the above-mentioned immediate, medium and long-term needs as well as prevent further deterioration of the situation, a coordinated approach among all involved was promoted in the implementation of Northern Floods Reconstruction Programme (NFRP) by the Ghana Government.

2 Areas affected by the flash floods

The three northern regions of Ghana, namely Upper East, Upper West and Northern were affected by the 2007 flash floods. According to the Ghana local Government Act 462, there are 38 administrative districts in these three regions and 29 of them were affected. The total land area of the three northern regions is estimated at 95,000 km² and a total estimated population of 4,000.000, which represents about 18% of Ghana’s total population and about 40% of the total land area. The affected area is shown in figure 1.

3 Facilities and infrastructure destroyed

The intensive nature of the floods destroyed both private and public infrastructure for social and human development, as well as farm produce. The floods destroyed cropped fields and washed away household stocks, seed stocks and livestock. The floods also destroyed point sources (boreholes and hand dug wells), domestic houses and road infrastructure.

Figure 1: Map of Ghana showing affected areas.

4 Implementation arrangement

4.1 Institutional structure for implementation

Start-up workshop was organized before the commencement of the programme. The aim was to involve all stakeholders in the planning and implementation of the programme. Responsibilities and roles of the various stakeholders were discussed and agreed upon. Figure 2 gives the overall implementation arrangement of the programme.

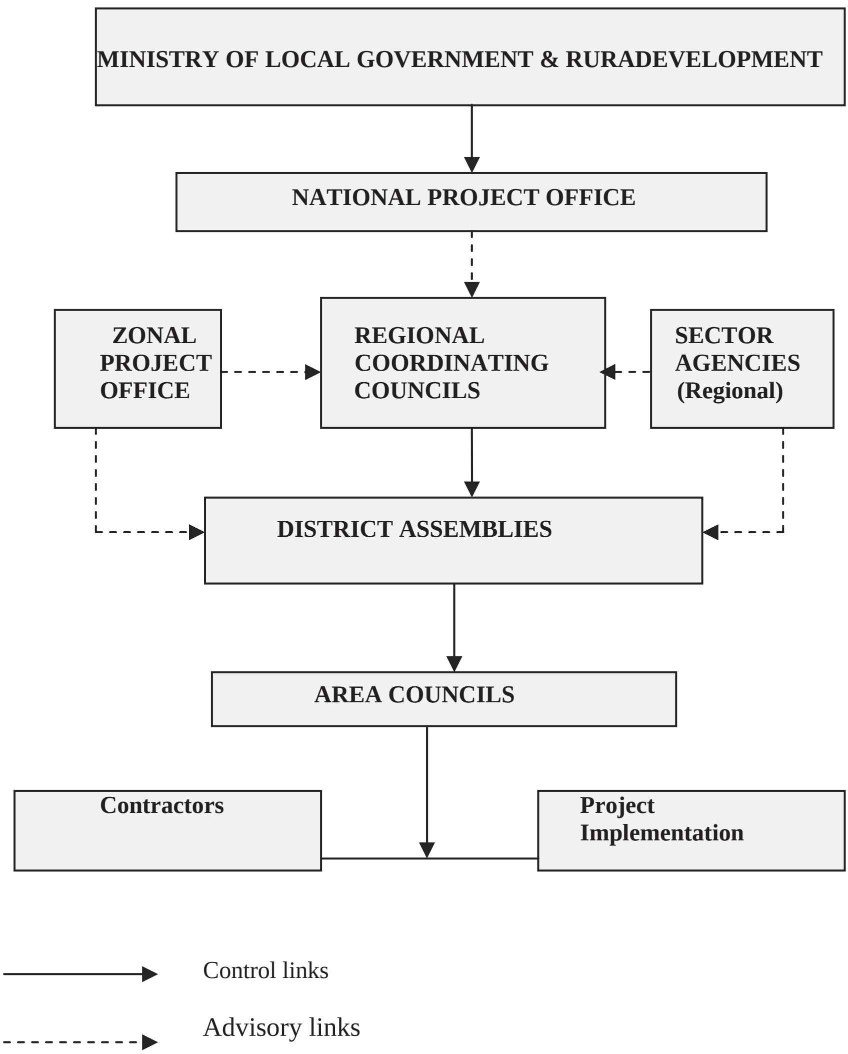

Figure 2: Implementation structure.

The Ministry of Local Government and Rural Development (MLGRD) on behalf of the Ghana Government had the oversight responsibility of the programme. The ministry provided policy and administrative direction to the implementation of the programme. The ministry was also responsible for the monitoring and evaluation of the programme and this was made easy by the quarterly reports that were submitted by the project office to the ministry.

The CBRDP project head office provided technical support to the Regional Coordinating Councils (RCCs) and the other sector agencies in the region in the implementation of the project. The project office also served as the link between the Ministry and the implementing agencies. The CBRDP Zonal Offices and other regional agencies provided technical advice to the Regional Coordinating Council. The Regional Coordinating Council had the immediate supervisory responsibility over the District Assemblies. The RCCs coordinated and harmonized the activities of the DAs. The RCCs also reviewed and gave recommendation to the activities of the District Assemblies. The sector agencies also provided technical advice to the DAs. The District Assemblies were the direct implementers of the programme. All key decisions and activities such as the procurement processes (i.e. tender advertisement, evaluation of tenders, contract award etc) and approval for payment were done by the DAs. The DAs had supervisory role over the Area Councils, which in turn monitored the Community Implementation Committee (CIC) and the private service providers.

4.2 Allocation of funds to district assemblies

The overall amount needed to comprehensively repair damaged public infrastructure was estimated at over USD$100 million, however, the funds that was made available by the World Bank and IFAD totaled USD $7,800,000. The funds were also only to be applied to public infrastructures that were eligible under the Project Development Objectives (PDO) of CBRDP and NORPREP. Mechanism for the distribution of the funds was then developed. The criteria were based on the underlisted procedure. Details are presented in table 2.

4.3 Procedure/steps for fund allocation

1. The damaged infrastructures that were eligible under CBRDP/NORPREP in the affected districts were identified (column 3 of table 2). This was determined from the field assessment by stakeholders (CBRDP Annual report, 2008).
2. Identification of parameters and assigning weights depicting the relative importance of the parameters. Refer to table 2 columns (4, 5, and 6). The parameters were assigned weights totaling 10 points. This was sourced from available national data.
3. Development of a scoring scale with a range of 1 to 6 to score the six subproject types against the weighted parameters to arrive at total scores and subsequent ranking of affected Districts.

4. The assessment matrix (table 2), was used to determine individual beneficiary DA's total scores and the relative percentage score of each DA as against the total scores of all DAs.
5. Each DA's allocation was arrived at by multiplying it's relative percentage score by total fund available ($7.80 million)

4.4 Procurement procedures

Although the programme was to be implemented under emergency conditions, procurement procedures in the recruitment of service providers were adhered to. The World Bank and Ghana Government's procurement guidelines were used concurrently. The various stages of the procurement process are presented in table 1.

Table 1: Procurement processes for the disaster reconstruction activity.

Stages	Procurement Activity	Approach	Outcome	Average time/week
1	Preparation of Tenders	Preparation of bidding documents was decentralized. In selecting the requirements, lower times were chosen and documents easier to be obtained chosen (bid securing declaration was used instead of bank guarantee or bid bond)	Each DA prepared their own tender documents with the support of the RCC and Project office	1
2	Advertisement of bids	Central advertisement was used	This reduced cost (up to 65%)	2
3	Submission of bids	This activity was decentralized. Bids were submitted to the various DAs	This allowed for a lot of bids to be received in one day	1 day
4	Evaluation of submitted bids	Central evaluation was done. CBRDP engineers all over Ghana were deployed for the evaluation. Process was supervised by RCC	This saved time (up to 70%)	1
5	Award of Contracts	This activity was decentralized.	This saved time	2

Table 2: Funds allocated to district assembly.

No.	DISTRICT TOTAL MAGNITUDE OF SOCIO-ECONOMIC IMPACT	DISTRICT TOTAL POPULATION AFFECTED	WEIGHTS TO DISTRICT TOTAL AS SHARE OF TOTAL		DISTRICT'S TOTAL INDEX	DISTRICT ALLOCATION = DA's Total Index * US$ 6,800,000	RANKING
			MAG. OF SOCIO ECONOMIC IMPACT	POPULATION AFFECTED			
D1	1,152	34,082	0.010427227	0.009579155	0.020006381	156,049.77	**15**
D2	800	63,017	0.00724113	0.017711683	0.024952813	194,631.94	**12**
D3	608	23,103	0.005503259	0.006493375	0.011996634	93,573.74	**20**
D4	624	9,599	0.005648081	0.002697914	0.008345995	65,098.76	**21**
D5	1,552	63,105	0.014047791	0.017736417	0.031784208	247,916.82	**10**
D6	80	2,963	0.000724113	0.000832787	0.0015569	12,143.82	**26**
D7	1,664	29,175	0.01506155	0.008199983	0.023261533	181,439.96	**13**
D8	2,128	29,893	0.019261405	0.008401786	0.027663191	215,772.89	**11**
D9	9,064	95,940	0.082041999	0.026965087	0.109007086	850,255.27	**3**
D10	5,600	148,456	0.050687907	0.041725338	0.092413246	720,823.32	**5**
D11	2,928	64,494	0.026502534	0.018126812	0.044629346	348,108.90	**8**
D12	5,912	148,506	0.053511948	0.041739391	0.095251339	742,960.45	**4**
D13	7,920	148,593	0.071687183	0.041763844	0.113451027	884,918.01	**2**
D14	4,336	186,681	0.039246923	0.052468933	0.091715855	715,383.67	**6**
D15	6,728	187,008	0.0608979	0.05256084	0.11345874	884,978.17	**1**
D16	2,000	100,587	0.018102824	0.028271182	0.046374006	361,717.25	**7**
D17	416	133,859	0.003765387	0.037622677	0.041388064	322,826.90	**9**
D18	160	53,637	0.001448226	0.015075322	0.016523548	128,883.67	**17**
D19	160	7,588	0.001448226	0.002132698	0.003580924	27,931.21	**24**
D20	64	10,008	0.00057929	0.002812868	0.003392159	26,458.84	**25**
D21	256	67,025	0.002317161	0.01883818	0.021155341	165,011.66	**14**
D22	224	53,569	0.002027516	0.01505621	0.017083726	133,253.06	**16**
D23	192	46,322	0.001737871	0.013019353	0.014757224	115,106.35	**18**
D24	32	1,871	0.000289645	0.000525867	0.000815512	6,360.99	**27**
D25	32	16,092	0.000289645	0.004522849	0.004812495	37,537.46	**23**
D26	512	27,352	0.004634323	0.007687607	0.01232193	96,111.06	**19**
D27	96	26,442	0.000868936	0.007431841	0.008300777	64,746.06	**22**
	55,240	**1,778,967**	**0.5**	**0.5**	**100%**	**7,800,000**	

D = Beneficiary District

Source: Project Assessment Report

4.5 The use rapid result approach

The Rapid Result Approach (RRA) was introduced to Community Based Rural Development Project (CBRDP) by Robert H. Schaffer & Associates (RHS&A) in 2006. CBRDP has since facilitated the use of RRA by Communities, Area Councils and District Assemblies in executing projects.

The main objective of Rapid Result Approach is aimed at jump-starting major change effort and enhancing implementation capacity. A Rapid Result Approach is also a planned effort designed to stimulate group adrenalin by galvanizing a team around the achievement of a meaningful, challenging results in a short period of time. This is done through the formation of groups and teams.

This approach was used under Northern Floods Reconstruction Programme (NFRP) in reconstructing some of the damage infrastructure. Changed agents formed were the Coach, Group leader, Strategic leader, Team leader and Team members.

This approach was used to reconstruct a damaged infrastructure within 100 days. The community under the supervision of Area Councils and District Assembly organized themselves for the reconstruction of the damaged facilities.

5 Challenges

5.1 Inadequate funding

The funds available was less than 10% of what was actually needed to effectively repair the damaged infrastructure caused by the 2007 flash floods that

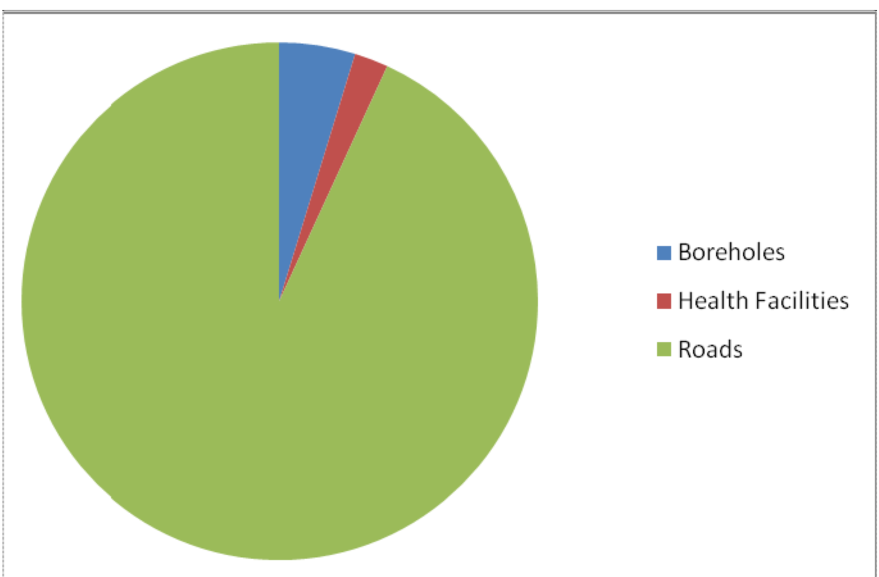

Figure 3: Percentage distribution of infrastructure repaired.

affected the northern part of Ghana. This posed a great challenge in the implementation of the programme. Some of the interventions proposed by some DAs were not adequate to address the problems caused by the floods. This was as a result of inadequate funds allocated to the districts.

6 Distribution of infrastructure destroyed

Various types of infrastructure were destroyed by the 2007 northern floods. However, only eligible projects under the World Bank funded CBRDP and IFAD funded NORPREP were repaired or worked on. With these criteria, the types of infrastructure that were eligible included water facilities, health facilities and road infrastructure. The distribution of infrastructures that were repaired after the intervention is as indicated in figure 2. This distribution resulted from the cumulative funds spent on the damaged infrastructure, which was proportional to the number affected.

6.1 Rules and regulations of sector agencies

The use of existing institutions proved successful in the implementation of the programme. However, coordinating the rules and regulations of individual institutions created a big challenge in the implementation.

6.2 Abuse of procurement procedures by some DAs

Although stringent measures were put in place to ensure that no abuse of procurement procedures, some DAs nonetheless went against the tenets of Ghana procurement Act, 663 and World Bank procurement guidelines and had to be corrected. It must be emphasized this was on minor scale.

6.3 Monitoring

There was the need for constant and regular monitoring of the implementation process by the implementation agencies to ensure quality of work and to meet deadlines. Considering the fact that these projects were scattered in 29 districts of the three northern regions made monitoring very expensive and challenging.

7 Lessons learnt

A lot of useful lessons could be learnt from the implementation of the Northern Floods Reconstruction Programme in Ghana, which could be particularly useful for similar programmes in other developing countries. Some of the major lessons learnt are:

7.1 The use of existing structures

The use of existing recognized institutions and bodies facilitated the implementing of Ghana's Northern Flood Reconstruction Programme (NFRP).

No new parallel structures were created. This helped in the maximization of resources and made the implementation of the programme reasonably smooth. Considering the emergency nature of such programmes it would be very beneficial if existing structures are employed in future programmes instead of creating new ones.

7.2 Meeting the needs of the people

The design of the programme took into consideration the major specific impacts of the floods on affected communities and districts. The initial inclusion of beneficiary district assemblies and communities in the identification of damaged infrastructure and the required interventions created an integrated approach in the implementation of the programme. This integral approach increased the communities' willingness to participate in the programme. It will be useful for future flood reconstruction programmes if the major needs of local communities are included in the fundamental objectives of the programme.

7.3 Participation of stakeholders

Full participation of community members is very essential for a successful integrated programme, this confirms the assertion by Rosenfield and Wilson. The involvement of community members at the very beginning of the programme helped in tapping their indigenous knowledge, which aided local members to consider themselves as partners of the programme.

7.4 The use of effective organizational structure

A proper organizational structure is very important in such integrated programme. This helps in clear representation and understanding of roles and responsibilities of stakeholders. Duplication of activities and conflicts are avoided or reduced when proper organizational structures are put in place.

8 Conclusion

The experience of the Northern Floods Reconstruction Programme implemented by the Ghana Government through the CBRDP suggests that, despite the constraints, which complicate the implementation of such emergency programmes, potential exists for effective implementation of such programmes if they are carried out in an integrated manner. It demonstrates that stakeholder-based participation is crucial in organising and managing such programmes. By identifying all stakeholders involved and ensuring their active participation can avoid power struggle among existing structures and thus perpetuating conflicts between elite stakeholders and local communities. The use of existing institutions/agencies instead of creating new ones speed up implementation process and ensuring early completion of such projects, this according to Banga and Sharma, are critical in emergency situations.

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Best practices for psychological support of communities after a disaster

B. Selzler & D. Grandbois
University of North Dakota, North Dakota State University, USA

Abstract

Historically, the U.S. emergency response system has not provided psychological support to communities impacted by disaster. Instead, the traditional emergency response community focused on preparing for and ensuring the physical survival and safety of the individuals and communities that it protects. However, since the terrorist attacks of September 11, 2001, private and public agencies have enhanced the capacity to respond to the behavioral health impact of disasters both on the community and individual. The goal of all disaster intervention, whether physical or psychological in nature, is to restore the individual to his/her level of pre-disaster functioning. The purpose of this paper is to identify the best practices and evidence-based strategies used to restore communities to pre-existing disaster functional status. A review of the important insights gleaned from U.S. terrorist attacks and from post-Katrina findings reveal many states' practices are limited to providing clinical services or psychological debriefing designed to directly mitigate or lessen the severity of the psychological impact on victims, responders, and nearby community members. Little attention has been paid to the broader psychological, social, functional, and behavioral issues that can impair recovery efforts for both individuals and the communities in which they reside. Helping communities become resilient and recover from devastation in a timely manner will improve the health of communities and decrease economic losses due to lost work time, health care visits, and use of substances to cope.
Keywords: disaster, behavioral health, mental health, resilient communities.

WIT Transactions on the Built Environment, Vol 119,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110261

1 Introduction

Effective psychological support planning for disasters requires that planners have a working knowledge about the range of reactions that are likely to be encountered among survivors, responders, and other helpers. For example, what community groups may be especially vulnerable to negative mental health consequences and what interventions are best, given the nature of the event and the population affected. The need to coordinate the delivery of planned responses across various systems of care and the wide array of community organizations and agencies require broad-based collaborations and solid understanding of best practices with respect to healthy partnership formation and maintenance. Research has identified a range of behavioral responses that people, and communities may have to traumatic events.

Most individuals who experience a catastrophic event do not develop diagnosable psychiatric illness, but the majority report experiences such as sleep disturbance, loss of concentration, or feeling emotionally upset afterward (Norris et al. [1]).

Exposure to a traumatic event affects people in different ways, from feeling mildly upset to having diagnosable behavioral and psychiatric symptoms. Those falling in the latter category most commonly show increased rates of acute stress disorder, posttraumatic stress disorder (PTSD), major depression, panic disorder, generalized anxiety disorder, and substance use disorder (Kaniasty and Norris [2]). Other symptoms associated with exposure to trauma or terror include: impairment of the immune system; non-clinical depression and anxiety; detrimental changes in eating patterns and other, subsequent ill health effects (e.g., stomach pain, intestinal problems, too little or too much sleep, ongoing fatigue). Individuals often have increased levels of risk-seeking behavior (e.g., increased alcohol or substance abuse) coupled with abandonment of usual care-taking behaviors (e.g., increased sexual activities with multiple partners, engaging in risky, unprotected sex acts). Emergency workers, people caring for survivors and others vicariously experiencing the trauma of the disasters, but who are not directly exposed, can experience debilitation from symptoms associated with secondary trauma that may persist for years after the event (Marmar et al. [3]).

In comprehensive literature reviews of the mental health effects of natural and human-caused disasters [1, 5], researchers found that for natural disasters, symptoms of PTSD tend to resolve within 18 months, although they may last for as long as three years. Among victims of human-caused disasters, reviewers found that PTSD, other anxiety disorders, depression, and somatization tend to persist longer, although the proportion of people with symptoms declines over the years.

Myriad factors influence the likelihood that an individual within the community will develop serious or lasting psychological problems in the wake of disasters. Gender; age; prior experience; ethnicity; culture; socioeconomic status (SES); family structure; problems of children, parents, or spouses; severity of exposure; secondary stressors; predisaster psychiatric history and personality; all appear to play a role [1].

2 Recent research on behavioral health

Research focused on recent and previous disasters provides important information about effective interventions that will routinely be needed following disasters at local, state, and national levels. These key interventions include:

- **Behavioral health triage.** Triage of physical injuries, or the sorting and assigning of treatment according to urgency, is a well established practice in medicine. Mental health concerns also should be triaged. Following a large-scale disaster, a range of developmentally and culturally appropriate treatment modes based on varying levels of need, acuity, and intensity are required. During the time it takes to minister to physical needs, a systemic and comprehensive mental health screening program can be implemented. One example of this kind of program is found in the New York response to the 9/11 terrorist attacks that included a program in which Mount Sinai Medical Center conducted physical health screenings in coordination with crisis counselors who provided psychological first aid and screened for more serious mental health disorders.

- **Multiple treatment modalities.** Treatment should be research-based and include community natural support networks. Some examples of evidence-based interventions include cognitive-behavioral therapy (CBT) e.g., Ruzek et al. [4] eye movement desensitization and reprocessing (EMDR) e.g., Shapiro and Maxfield [5], as well as other therapies. It is crucial to ensure that these are administered by trained and experienced counselors. Damage can be done by well-meaning helpers who are not adequately qualified. One potentially effective approach revolves around the establishment of a pool of qualified therapists in advance or in the immediate aftermath of a disaster. In New York, Dr. Randall Marshall and his team trained 1,500 mental health workers in proven trauma treatments so they could work in their own communities following the 9/11 terrorist attacks. This proved to be an effective model.

- **Credential and screen staff.** In the chaos of a disaster, many helpers flock to the scene. Communities should define in advance the various roles that will be enacted following an attack or disaster and the criteria for people qualified to fill those roles. Only qualified people trained for a specific disaster should then be allowed to fill that role. This qualification applies to all people working on the front lines: emergency workers, mental health workers, and faith-based counselors. Optimal planning would include advanced training (Butler et al. [6]). In Utah, the state disaster coordinator developed a training series that led to psychological support credentials for professional mental health workers. The wrong mental health treatment can do more damage than no mental health treatment.

2.1 Phases of reactions

Other research documents phase in reactions of individuals and of communities following disasters (i.e., heroic-honeymoon phase; disillusionment phase; retaliatory-blaming phase; and recovery phase). Such information allows behavioral health planners to anticipate the need for the delivery of specific and timely individual and community interventions. For example, in the heroic-honeymoon phase, many people need information about the “normal” and expected responses to their trauma experience. In later phases of disaster, as disillusionment and the pain of losses accumulate, education may be needed to redress stigma or retaliatory acts and hate crimes that can emerge [1].

2.2 Recovery from trauma

Other significant research has identified interacting factors that may determine both short-term functioning and long-term adaptation to traumatic events for individuals and social groups (i.e., the psychosocial model of disaster) (Korol et al. [7]) with a special focus on reactions that children and adolescents may experience. These factors include (1) characteristics of the stressor (i.e., extent of loss, life threat); (2) cognitive processing of the event (i.e., magical thinking, appraisal); (3) individual characteristics of the child (i.e., age, sex); and (4) characteristics of the environment (i.e., reactions of family members). The psychosocial model proposed by the authors uses a developmental perspective in which the individual’s reactions are anticipated. Such studies not only help identify needed individual-level interventions, but also are critical for anticipating and devising interventions that will be needed for wider distribution or targeted for use with certain age groups or subpopulations. For example, targeted outreach may be needed for members of cultural groups that routinely eschew use of public care systems or for use with groups of people living with predisaster psychiatric disabilities or substance use disorders.

2.3 Theories of behavioral health

Public Health theories can inform intervention practices in that a comprehensive working knowledge of the community is needed before disasters occur. Emergency behavioral response planners need to know who is in the community (e.g., enclaves of low-income, disabled, elderly, ethnic or cultural members), the nature of its current infrastructure (e.g., hospitals, clinics, shelters, congregate housing sites, geographic features, transportation, communication mechanisms), the composition of local and state social services and care systems (e.g., workforce, housing, governmental and nongovernmental agencies, and the range of qualified behavioral health responders in the area (e.g., clergy, emergency workers, mental health workers). In short, a comprehensive community assessment focused on disaster response is imperative in planning for the future.

3 Emergency planning

Emergency planning in this century confronts new realities and needs to incorporate the lessons learned from recent tragic events in the United States. In the national struggle to confront and resolve the mental health issues associated with – and exacerbated by – disasters, the lessons learned during two catastrophes in the United States, the 9/11 terrorist attacks and Hurricane Katrina, are particularly instructive. The aftermath conditions of these disasters exemplify a range of individual reactions and structural issues that need to be anticipated so that effective responses to the complex mental health needs that emerge after disasters can be marshaled.

Terrorist activities in 2001 challenged the United States to learn new ways of responding to devastating crises that would provide a sense of safety and security to the public. A retrospective summary judgment about the nation's lack of preparedness to redress psychological damage associated with terrorist-instigated disasters was noted in a 2003 Institute of Medicine report:

> The nation's mental health, public health, medical, and emergency response systems currently are not able to meet the psychological needs that result from terrorism. Gaps exist in the coordination of agencies and services, training and supervision of professionals, public communication and dissemination of information, financing, and knowledge- and evidence-based services Institute of Medicine [8].

4 Lessons from terrorist attacks

Following the 9/11 terrorist attacks, the extent of psychological impact became apparent and the need for a well-coordinated public mental health response system to prepare for terrorism was emphasized (ibid).

Numerous studies (Schuster et al. [9], North et.al. [10], Schlenger et al. [11], Silver et al. [12]) have examined the mental health consequences of major terrorist attacks experienced in the United States (i.e., Oklahoma City bombing, the World Trade Center, the Pentagon, and the anthrax attacks in 2002-2003). As a whole, the studies revealed that the effects from acts of terrorism on mental health affected a higher percentage of people and that the effects were more enduring than the negative psychological outcomes reported in previous studies for natural or accidental disaster survivors. Salient findings from some of these studies are highlighted below.

- The Schuster et al. [9] study, conducted three to five days after September 11, 2001, found that 44 percent of the adults surveyed reported one or more substantial symptoms of stress, and 90 percent had one or more symptoms. The study also identified a relationship between time spent watching replays of the attacks on television and reported increases in anxiety, sleep disturbance, and generally low or depressed mood.

- Silver et al. [12] found that respondents' use or abandonment of coping strategies in the aftermath of the 9/11 terrorist attacks operated as predictors of long-term distress.

- Cardenas et al. [13] examined the effects of 9/11 terrorist attacks on a Midwestern university population 600 miles from New York City. Two years after the attacks, 76.5 percent of the study participants reported experiencing PTSD criteria of fear, helplessness, and horror four to six months after the event.

- Boscarino et al. [14] investigated the levels of fear of future terrorism in New York one year after September 11, 2001. Approximately half of those surveyed expressed considerable fear of further attacks, including future biological and nuclear attacks.

- Multiple negative mental health effects were found not only for residents directly exposed to the terror attack, but also by those indirectly exposed via disturbing media images (Butler et al. [6], Galea et al. [15], Marshall and Galea [16]). The symptoms of individuals who were indirectly exposed to the attacks via the media can be as intense as those directly exposed. Prolonged, repetitive exposure to the horrific images of terror may contribute to ongoing heightened levels of posttraumatic stress and related mental health problems in the wider society well after the actual attack [12].

4.1 Lessons from Hurricane Katrina

Recent findings from studies of the psychological outcomes after Hurricane Katrina in 2005 both underscore and expand the knowledge gained about survivors' psychological distress from 9/11 experiences and the aftermath (e.g., Wang et al. [17], Kessler et al. [18], Galea et al. [15], DeSalvo et al. [19]). Many of these studies stand in contrast to findings from other disaster studies, where post-disaster mental disorders typically decrease with time. Highlights of some of these post-Hurricane Katrina summary findings include:

- Among Hurricane Katrina survivors, PTSD, serious mental illness, suicidal ideation, and suicide plans prevalence increased significantly. Unresolved hurricane-related stressors accounted for large proportions of the increases in the incidence of serious mental illness [18].

- Eighteen months after Hurricane Katrina hit, of those who had used mental health services before the storm, 60 percent had stopped using

www.witpress.com, ISSN 1743-3509 (on-line)

them [17]. Under treatment was greatest among respondents who were younger, older, never married, members of racial or ethnic minority groups, uninsured, and of moderate means. Structural, financial, and attitudinal barriers were frequent reasons for not obtaining care [18].

- Hurricane Katrina survivors with mental health disorders experienced unmet treatment needs, frequent disruptions of existing care, and widespread failure to initiate treatment for new-onset disorders. Future disaster management plans should anticipate both types of treatment needs [17].

4.2 Capacity building

Researchers have observed that whether or not the cause of a disaster is attributable to humans or to nature, the impact is a reflection of social forces (Calderon-Abbo [20]). To prepare for disasters, post-disaster planning and implementation require building and maintaining infrastructures and service networks that can support the delivery of services to everyone affected, but especially to people with special needs (e.g., children, frail older adults, people with cognitive disabilities, people who have mental or physical illnesses).

In consideration of the findings reviewed above, the scope of entities and actors involved in collaborations must be broadened and must encompass representatives from community institutions and care systems to ensure that outreach to special populations, and mental health assessments, are completed in a timely fashion after disaster strikes. In addition, a broad swath of community actors that represent local social service systems will help reduce the extensive under-treatment effects that Hurricane Katrina survivors report. Emergency planning needs to incorporate attention to ongoing and long-term recovery needs for disaster survivors that simultaneously builds and nourishes community resilience.

A well-coordinated public mental health response system requires joint planning and exercising with all possible partners. Public health, emergency management, law enforcement, and medical response teams are clearly central figures in planning and post-disaster intervention work, but lessons from Hurricane Katrina studies indicate that the addition of representatives from business communities, civic and faith-based organizations, advocacy organizations, schools, community-based clinics, and special needs facilities are needed to improve the breadth of effective behavioral health responses available.

While great strides have been made over the past few years with regard to increased collaboration and partnering across disciplines, much work remains to be done. The languages spoken across disciplines – disaster responders, public health, mental health, and others – vary widely. Priorities and ways of doing business in disaster vary as well, with disaster responders adhering to an incident command structure that is quite foreign to "civilian" responders, which includes most behavioral health responders.

The level of integration between disaster behavioral health and emergency response varies considerably across states and territories. In some instances, disaster behavioral health responders can be found at the incident command center. In other instances, they are never called upon.

Few states have emotional support programs ready and able to address the myriad needs of people affected by disaster. Nationally there is not a credential or certification for individuals who would be called on to provide emotional support. Traumatized populations often suffer from many common attributes that render specialized psychological training critical, both interculturally and within a single society that shares common customs and outlooks. The inability to provide effective intervention to traumatized populations is likely the greatest psychological need in the world today. Danieli [21] and others have shown that the psychological effects of conflict are passed on through generations, from parent to child, making the effects of trauma more intractable. The literature on historic trauma helps us better understand the need for local, regional, and state support for those who have experienced a disaster or traumatic event. For children in particular, a community-wide trauma may leave a lasting impression. As the capacity for a child's mental concentration is diminished in response to the intrusion of traumatic memories or associated fears, so is the child's ability to play, and hence to learn and think creatively. Following a series of West Virginia floods that resulted in considerable destruction and some loss of life, teachers reported that children in their classrooms would begin to cry at the first sign of rain. Through an ongoing federal grant, teachers requested additional support from counselors with expertise in post-disaster behavioral health to address the children's emotional needs and assist them in coping with the traumatic memories (and for some, loss of home, possessions, or family). Support is occasionally available within existing community structures and by traditional means, but it is often the case that local mental health professionals have themselves been traumatized and suffered physically and psychologically, resulting in a diminished capacity to respond to the community needs.

5 Conclusion: recommendations for disaster planning and response

Knowledge from research regarding post disaster behavioral health and the need for psychological support can guide planners to support community resilience. It is essential that disaster managers and planners understand and plan for emotional upheaval of the community. Behavioral health responders need to recognize how and why post-disaster behavior influences the effectiveness of intervention. Education and communication are the medium for psychosocial interventions. To ensure psychosocial and behavioral health preparedness before disasters occur, disaster planners must engage community decision-makers in assessing longitudinal needs and help plan for the needs of a community in recovery. Keys to this include:

- **Assessing mental health symptoms.** Planners must assess and determine the extent of use of alcohol and drugs, social support availability and needs, social service economic needs, and interagency information sharing that will facilitate sharing and stretching available resources, including staff.

- **Community assessment.** This would include measuring resilience and document the anticipated influences of significant psychological impacts on all residents and for special groups within the community.

- **Identifying and applying brief psychological interventions to reduce traumatic stress reactions.** Exposure and cognitive restructuring are the core elements of this intervention and have been shown to be effective in treating chronic PTSD (Foa and Rothbaum [22], Resick et al. [23]. The success of these treatments with both acute stress disorder and chronic PTSD suggests that it may be appropriate to deliver some aspects of these interventions to disaster survivors.

- **Communicating known or possible limitations of identified interventions.** The most powerful elements of the effective interventions are thought to involve exposure therapy and cognitive restructuring (a.k.a., cognitive therapy), and possibly anxiety management (including breathing retraining and relaxation). However, since it appears that adding anxiety management does not increase the effectiveness of an exposure/cognitive restructuring package (Bryant et al. [24]), this component should be studied as a stand-alone early intervention. Cognitive therapy is an intervention that may be relatively less emotionally provocative and may be more familiar to some clinicians. Disaster counselors often address negative cognitions, such as misinterpretations of acute stress reactions, guilt and shame, and negative beliefs about the future, albeit informally. Counselors should receive education about the role of cognition in development of PTSD (Ehlers and Clark [25]) and training in more systematic approaches to modification of distressing disaster-related beliefs.

- **Screening for alcohol use.** Identifying and applying brief alcohol use interventions. Research on brief alcohol interventions has shown that such services can lower alcohol consumption e.g., Heather [26]. Particularly relevant is a demonstration that a single session of counseling can reduce drinking in patients recently treated in hospital trauma centers (Gentilello et al. [27]).

- **Identifying survivors at risk for long-term problems.** One of the key functions of mental health workers is a referral of survivors for mental health treatment. Information from studies that document risk factors affecting development of PTSD and other negative sequelae in the contexts of disaster and traumatic stress will advance this objective (Brewin et al. [28], Norris et al. [1]). Additional training in risk factors and in use of screening instruments may help disaster workers better identify survivors who may benefit from referral to mental health services that are more intensive than brief education and support.

Current behavioral health responses to large-scale public health emergencies have not yet incorporated some of the important insights gleaned from U.S. terrorist attacks or Hurricane Katrina findings. Learning about the effect of psychological support on communities after recent tragic events will enhance the nation's ability to respond and recover from future events. Assessment of both individuals and community resilience is needed to plan specific, culturally appropriate interventions. Tools for assessment should be developed and tested. Screening for co-occurring mental, physical and drug/alcohol abuse will help to target appropriate interventions and referrals. Early screening may also identify those at risk for long term complications. An educated, skilled workforce is needed to provide behavioral health when a disaster occurs. It is important for planners to partner with key community organizations and to identify what each community needs in order to recover from a disaster.

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Farmers' awareness and utilization of disaster management strategies and training needs for sustainable food security and livelihoods in Nigeria

N. T. Meludu
Department of Agricultural Extension and Rural Development, University of Ibadan, Nigeria

Abstract

Disasters are extremely harmful to people and cause considerable loss to national economies. Food production in rural areas is especially vulnerable to disaster. Disaster management is therefore extremely important everywhere in the world, especially in developing countries. Agriculture concerns food production, and the consumption of food is a primary life prerequisite for all human beings wherever they are living on the globe. Agriculture is also one of the economic sectors that turns out to be the most affected by disasters. Integrating agriculture, livelihoods and environmental issues into disaster response efforts and risk reduction strategies is particularly important for poor communities, often resident on marginal lands, which are at greatest risk of natural disasters. That is the reason why this study is focused on the awareness and utilization of strategies for disaster management in agriculture. The result revealed that the higher percentage (55%) of the respondents ranked flooding as the most severe risk, followed by erosion (20%), pollution (10%), and pest and disease outbreak (5%) respectively. The majority of the respondents showed high training needs in the entire preventive and control methods of disaster risks. This corresponds with the respondents' lack of awareness of the disaster management strategies and the kind of risk these people face. This is an indication that the respondents have not received any training on disaster management and could be adopting poor strategies or no strategy at all. However, there is significant relationship between marital status (χ^2 =5.134; p = 0.014) and level of education ((χ^2 =17.678; p = 0.001) and awareness. It was discovered that some of the farmers

WIT Transactions on the Built Environment, Vol 119, © 2011 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/DMAN110271

lack the capability to effectively manage disaster, thereby losing their livelihoods. In making disaster risk reduction strategies more effective, a comprehensive approach to disaster management involves a number of actors and actions outside the expertise and realm of environmental organizations.
Keywords: livelihoods, environment, disaster, mortality, awareness, risk reduction, strategies, training, utilization, Nigeria.

1 Introduction

Globalization in the agricultural industry is increasingly competitive. In recent years, the world has witnessed a succession of disasters—floods, wildfires, storms, earthquakes, volcanic eruptions, and landslides. These claimed many thousands of lives, caused material losses in the billions of dollars, and inflicted a terrible toll on developing countries in particular, where disasters divert attention and resources from development needed desperately to escape poverty (UNDP [1]). It is a well-known fact that today's disasters are often generated by, or at least extended by, human activities (FAO [2]). At the most dramatic level, human activities are changing the natural balance of the planet and interfering with the atmosphere, oceans, polar ice caps, forest cover, and the pillars that make our world what it is (ISDA [3]). Population growth and associated pressures cause more people to live in flood plains or in areas prone to landslides. Inadequate land-use planning, poor environmental management and a lack of appropriate institutional and legislative arrangements increase the risk and multiply the effects of disasters. Living with risk is the order of the day, and there is the need to learn to reduce these risks through appropriate measures focused on planning, forecasting, and mitigation. There is the need to build a world of resilient people, communities, and nations. Gradually, environmental and development stakeholders are becoming more involved in the management of risk and vulnerability reduction due to their close interaction with natural resources management by creating awareness (Tigere Chagutah [4]).

The African Ministerial Statement to the World Summit on Sustainable Development states that the increased incidence of natural disasters in Africa poses a major obstacle to the African continent's efforts to achieve sustainable development, especially in view of the region's insufficient capacities to predict, monitor, handle, and mitigate natural disasters (South Africa [5], Marjanovic and Nimpuno [6]). Reducing the vulnerability of the African people to natural disasters and environmental risks is mentioned as a requirement to achieve the poverty reduction goals of the Millennium Declaration alongside other basic requirements, including economic growth, access to sources of energy, and basic health services. Nigeria has been experiencing quite a significant number of disastrous events of both natural and anthropogenic origin. Recent information on the hazard profile of the Nigeria and its vulnerability and capacity assessment shows that these disasters are related to drought, water and climate, fire disasters, locust invasion, environmental degradation, floods and epidemics. Disasters have caused great losses to lives and properties in Nigeria and have often pushed several people into poverty. The economic impact of disasters usually consists of direct damage e.g. infrastructure, crops, animals, housing, and indirect damage. The aftermath of these disasters is that it results to loss of revenues, unemployment and market destabilization. It is therefore increasingly becoming a major developmental issue of urgent concern for the government, development partners and local communities. Over the years, Nigerians have had to rely on share luck and providence to save them from disasters with little or no help coming from rescue agencies which lacks the capacity and wherewithal to intervene in such difficulty moments. Disasters derail socio-economic progress, and put millions of people into terrible poverty or make the poor even poorer. The need to systematically reduce the increased impact of disaster is steadily gaining recognition and commitment of government worldwide.

In 1990, Nigeria along with other member countries of the United Nations set up a National Committee for the International Decade for Natural Disaster Reduction (IDNDR). The Nigerian Inter-Ministerial body set up four sub-committees, with NERA retaining membership in each sub-committee, to address natural disasters reduction in Nigeria. A working group was also inaugurated with a representative from NERA to work out a situation report on Natural Disaster reduction for the country for the remaining years in the decade. This report was submitted in May 1994 and after this submission, the committee ceased to exist. This brought back the task of drawing up a National Agenda on the issue of disaster management in all its ramifications. This function of NERA with regards to Disaster Management was very limited because of the scope under which it operated. The National Emergency Management Agency (NEMA) was established via Act 12 as amended by Act 50 of 1999, to manage disasters in Nigeria. The establishment of NEMA, for more than ten years ago, ushers in a new dawn in disaster management from the hitherto narrow practice of relief distribution. Bracing up to the challenges of its given mandates, efforts were continuously made in putting together the necessary structures and sustained refocusing of programmes towards efficient and effective disaster management in the country. For the country to have an effective disaster management required “political and legal commitment, public understanding, scientific knowledge, careful development planning, responsible enforcement of policies and legislation, early warning systems and effective disaster preparedness and response mechanisms” (Audu-Bida [7]).

The authorities of the NEMA had rolled-out a three-year action plan since 2009 to train more than 154,800 volunteers on effective disaster response and control mechanisms. The focus at the flag-off a 3-day sensitization workshop on Disaster Risk Management for Public Officers in Kaduna that it planned to engage in the training and mobilization of 154,800 volunteers as part of Federal Government’s new contingency plan to management disaster incident in the country. It was emphasized that about 200 volunteers would be drawn from each of the 774 local government areas of the country and would be adequately trained and equipped with all the techniques and skills to ensure prompt and effective response action during disaster. Disaster management requires not only emergency relief but political and legal commitment, public understanding, scientific knowledge, careful development planning, responsible enforcement of policies which should be responsive and proactive for the effective management of any emergency. While regretting the enormous loses that trail every disaster incident in the country in the past years. One major fall-out from the workshop is that while the number and gravity of disasters are on the increase locally and globally, the traditional strategies for disaster management through relief measures have become ineffective because they are largely reactive instead of being proactive in reducing the risk.

Disasters that were not properly managed have contributed significantly to loss of skilled personnel, diversion of scarce resources, and destruction of infrastructure, negative investment climate, political destabilization and loss of agricultural land. In the same vein, it was observed that the public, most especially the citizenry are not adequately informed and educated by the media and relevant information organs of government on potential areas of disasters, precautionary measures and expectations in case of disasters. While political and public attention has focused on the needs of urban areas, the state of preparedness among rural first-responder agencies has not been sufficiently addressed. Rural areas are home to nearly greater number of Nigerians and are the sites for food production security.

A substantial progress has not been made in incorporating disaster risk reduction (DRR) issues in educational system. Issues on hazards, vulnerability, DRR measures have not been placed in various text books from elementary-secondary to tertiary level of education. Different certificate courses, post-graduate diploma courses and Bachelor of Science are yet to be instituted. A regulatory and institutional framework for disaster management system is required to strengthen country's disaster management capacities. The challenges should be to have a paradigm shift from a reactive disaster response programme that is proactive to comprehensive risk reduction approaches, programme designing and implementation. Many public sectors officials posted for different disaster management agencies/responsibilities have experienced at some time in their careers the impact of flood they may not necessarily have the broader knowledge, skills set and experience required to enable them to drive strategic whole government risk reduction initiatives. In view of the longer term vision, it is important to strengthen the competency *(knowledge, skills and attitude)* of the people not only working in the national government system, but the common populace (example farmers) to be trained.

NEMA should be able to pre-empt devastating disasters in the country. In view of the fact that the media have active roles to play in creating public awareness on early warnings and proactive approach to curtail disaster, participants at the workshop were of the opinion that they should be involved in processes and programmes to achieve maximum results. Funding was seen as a major source of meeting target objectives and goals and as such, it was the general consensus that public awareness of disaster risk reduction should be adequately budgeted for by the government and donor agencies are made available for disaster management.

NEMA caters for the special interest of the most vulnerable groups during disasters, a new unit has been created under the department to address the issues of women and children including those of the handicaps.

Hitherto, disaster management in country was mainly humanitarian relief supplies with huge funds expended annually on perennial emergencies. The paradigm shift in disaster risk management offers a good opportunity to build, develop and sustain policies pertaining to social development, equity, economic growth, environmental quality and sustainable land use. Experiences have revealed that in disaster management attention should be given to prevention and mitigation rather than to wait for the aftermath. NEMA has developed a special programme in this regard and with the cooperation of the stakeholders to embark on a series of training, sensitization and initiatives to promote the required consciousness on specific and general disasters. The programme emphasizes on the mainstreaming of disaster management into national development policies. But the question is, how is the rural populace, especially the farmers, to be educated on disasters and disaster management strategies so that they do not feel that whatever disaster that is affecting their area is not that the gods are angry with them? Despite Nigeria's being rich in agriculture resources, the agricultural sector has been growing at a very low rate. Less than 50 percent of the cultivable agricultural land is under cultivation. Even then, small holders and traditional farmers who use rudimentary production techniques with resultant low yields cultivate most of the lands. The small holder farmers are often constrained by many problems including those of poor access to modern inputs and credit, poor infrastructures, inadequate access to markets, land and environmental degradation, natural disasters, inadequate research and extension services. Three out four people in the developing countries live in rural areas and are highly dependent on agriculture for their food and livelihood. Disasters tend to have the most severe consequences on poor, vulnerable and agricultural-based population.

Therefore, the main objective of this study is to determine farmers' Awareness and Utilization of Disaster Management Strategies and Training Needs for Sustainable Food Security and Livelihoods in Nigeria. Poor farmers are neither aware of the tools and techniques for disaster management nor have the capacity to pay the premiums. More work needed before their large scale adoption in the developing countries like Nigeria. This is due to the fact that farmer maintain self-help groups to manage their own stocks of food, storage, seeds climate change and natural disasters.

2 Methodology

The case study area is Ogun state where there was a heavy flood in 2009 and even in 2010 that swept many homes and farm lands into water. Apart from Abeokuta, the capital, which is an important market centre-and a terminus of the roads and railways coming from Lagos and other parts of the country, there are also major towns and communities like Sagamu, Ijebu-Ode, lIaro and others that can serve as good markets for products of the mining industry in Ogun State. Ogun State is entirely in the tropics. Located in the Southwest Zone of Nigeria with a total land area of 16,409.26 square kilometres, it is bounded on the West by the Benin Republic, on the South by Lagos State and the Atlantic Ocean, on the East by Ondo State, and on the North by Oyo and Osun States. It is situated between Latitude 6.2°N and 7.8°N and Longitude 3.0 o E and 5.0°E. The climate of Ogun State follows a tropical pattern with the raining season starting about March and ending in November, followed by dry season. The mean annual rainfall varies from 128cm in the southern parts of the State to 105cm in the northern areas. The average monthly temperature ranges from 23°C in July to 32°C in February. The northern part of the State is mainly of derived Savannah vegetation, while the Central part falls in the rain forest belt. The southern part of the State has mangrove swamp. The geographical landscape of the State comprises extensive fertile soil suitable for agriculture, and Savannah land in the north western part of the State, suitable for cattle rearing. There are also vast forest reserves, rivers, lagoons, rocks, mineral deposits and an oceanfront. Ogun State is blessed with many mineral deposits in commercial quantity. The list includes bitumen, kaolin, phosphate, bauxite, granite, limestone, crude oil and such others. The population of Ogun State during the 1991 Census was 2,333,726. With its growth rate of 2.83 per cent per annum, the population estimate for 2003 was projected at 3,297,408 and 3,486,683 for 2005. The projections indicated that in 2003, about 1,483,834 of the population (45 per cent) would live in urban areas 1,813,574 (55 per cent) in rural. Agriculture is the main occupation of the people, providing income and employment for a large percentage of the population. The State is blessed with a conducive climate that enhances cultivation of a variety of crops such as yam, cassava, maize, rice, plantain, beans, vegetables and citrus fruits such as orange, paw-paw, pineapple and so on. The main cash crops produced in the State are cocoa, cashew, kola nut, oil palm and palm kernels, rubber and coffee.

2.1 Sampling technique and sample selection

The population for this study involved all the farmers in the study area. Out of the twenty four local government areas in Ogun state, two (Ifo and Ogun waterside) LGAs were purposively chosen for the study because of the series incidents of floods and other disasters in the area which have affected agricultural production in the area. Fifty farm head of farm households were randomly selected for the study in each LGA, making a total of 100 respondents. Structural questionnaire with open ended questions was used to collect data from the respondents.

2.2 Data analysis

Data collected were subjected to both descriptive and inferential statistical analysis, such as frequency, percentage, and Chi-square.

3 Result and discussion

This section starts by presenting results on frequency and percentage on personal characteristics of the respondents.

Table 1: Distribution of the personal characteristics of the respondents (n= 100).

Personal Characteristics	Frequency	Percentage
Age		
20 – 29	5	5.0
30 – 39	15	15.0
40 – 49	20	20.0
50 – 59	36	36.0
60+	24	24.0
Sex		
Male	55	55.0
Female	45	45.0
Marital status		
Single	5	5.0
Married	95	95.0
Educational Attainment		
Non-formal education	31	31.0
Adult literacy	8	8.0
Primary school education	14	14.0
Secondary education	20	20.0
Tertiary education	27	27.0

Table 1 reveals that majority of the respondents (36%) are between the age range of 50–59 years old. Also substantial percentages of the respondents (24 and 20%) are between the ages of 60 and above and 40–49 years old respectively. Age is an important personal characteristic to determine how active the respondents are. Unfortunately, majority of the respondents are very old. This will affect them in actively participating in disaster risk management and may find it difficult to escape. Majority of the respondents (55%) are male while high percentage (45%) is female. This shows that more males are involved in agriculture in this area. This is also an added advantage because women are more vulnerable in disaster risks.

A high proportion of the respondents (95%) are married while very few (5%) are single. Married people are more respected in the study area and they are also more responsible and serious in their job. Education is very important in all human activities and will enable the respondents to acquire more training for sustainability of life. Table 4 shows that high proportion (31%) of the respondents had non-formal education, that is why few (8%) of the respondents have participated in adult literacy to help them cope in life. Majority (61%) had primary, secondary and tertiary education. This shows that rural people are becoming more educated in recent time than before.

Table 2: Distribution on sources of information by the respondents (n = 100).

Source of Information	Frequency	Percentage
Newspaper	5	5.0
Radio	15	15.0
Television	5	5.0
Friends/relations	15	15.0
Local leaders	25	25.0
Extension agent	5	5.0
Local means of passing information (i.e. town crier)	25	25.0
NEMA official	5	5.0

Table 3: Types of environmental risks in order of severity (n = 100).

Type of environmental problem	Rank in severity of the problem (Frequency)	Percentage
Flooding	55	55.0
Erosion	20	20.0
Pollution	10	10.0
Pest infestation	5	5.0
Disease out break	5	5.0
Drought	3	3.0
Fire	2	2.0

Table 4: Level of awareness of disaster risk factors.

Awareness of environmental risks factors	Low awareness (Frequency)	Percentage	High awareness (Frequency)	Percentage
Flooding	75	75.0	25	25.0
Erosion	65	65.0	45	45.0
Pollution	80	80.0	20	20.0
Pest infestation	55	55.0	45	45.0
Disease out break	85	85.0	15	15.0
Drought	78	78.0	22	22.0
Fire	50	50.0	50	50.0

Table 2 reveals that majority (25%) of the respondents receives information about disaster and disaster management from the local leaders and local means of passing information respectively. Fifteen percent of the respondents receive information from the radio. A high percentage, (15%) receive information from friends and relations. While very few (5%) of the respondents receive information from the newspaper and television respectively. The problem of epileptic power supply may not enable the respondents to utilize television.

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Table 5: Distribution of the respondents on training needs (n = 100).

Level of need		
Radio weather reading		
	Frequency	percentage
High need Low need	93 17	93.0 17.0
Training on flood prevent/control		
High need Low need	88 12	88.0 12.0
Erosion prevention/control		
High need Low need	78 22	78.0 22.0
Mobilize communities to take disaster preparedness		
High need Low need	87 13	87.0 13.0
Revival of indigenous food storage and prevention techniques and planting of trees		
High need Low need	56 44	56.0 44.0
Improved farming techniques		
High need Low need	78 22	78.0 22.0
Transferring the risk (Insurance)		
High need Low need	90 10	90.0 10.0
Water resources management		
High need Low need	86 14	86.0 14.0
Proper land use management		
High need Low need	67 33	67.0 13.0
Biodiversity conservation		
High need Low need	56 44	56.0 44.0
Pollution prevention and control		
High need Low need	66 34	66.0 34.0
Pests prevention/control		
High need Low need	70 30	70.0 30.0
Disease prevention/control/immunization		
High need Low need	91 9	91.0 9.0
Fire prevention/control		
High need Low need	67 33	67.0 33.0

Table 6: Distribution of the constraints faced the respondents (n = 100).

	Frequency	Percentage
Inadequate capital to cope with risk	68	68.0
Flood	97	97.0
Erosion	78	78.0
Pollution	68	68.0
Inaccessibility of good water	75	75.0
Diseases	68	68.0
Pest	45	45.0
High mortality	50	50.0
Lack of credit facility	82	82.0
Poor weather condition	79	79.0
Lack of labour	56	56.0

However, the can easily use battery to power their radios in order to receive information. Agricultural extension (5%) and NEMA (5%) who are actually responsible to the farmers and disaster information are not always available. Table 3 revealed that higher percentage (55%) of the respondents ranked flooding as the most severe risk, followed by erosion (20%), pollution (10%), and Pest and disease outbreak (5%) respectively.

Awareness generation is very important to determine whether the respondents are aware of the risk factors associated with natural disaster. This is because of the fact that the rural people have different believes when such risks occur. Some time they think that it is caused by witches and wizards and or a kind of bad omen. More than half of the disasters in the country are man-made arising from deliberate intent, error or negligence. Disasters of man-made origin can be minimized by arousing the consciousness of the people through awareness generation.

The Agency utilizes awareness generation against disasters as the cornerstone in building a culture of sustainable resilience to disasters. Table 4 shows that majority of the respondents have low awareness on the risk factors of disasters.

The importance of this type of training is with respect to the effectiveness of disaster response. Table 3.5 indicated that majority of the respondents showed high training needs in the entire preventive and control methods. This corresponds with the respondents' lack of awareness of the disaster management strategies and the kind of risk these people face. This is an indication that the respondents have not received any training on disaster management and could be adopting poor or no strategy.

Table 6 reveals that the major constraints faced by the respondents include inadequate capital to cope with risk (68%), flood (97%), erosion (78%), pollution (68%), inaccessibility of good water (75%), diseases (68%), pest (45%), high mortality (50%), lack of credit facility (82%), poor weather condition (79%) and lack of labour (56%). All these problems need to be addressed for sustainability of agricultural production, food security and livelihoods.

Table 7: Chi-square statistics on the relationship between personal characteristic of the respondents and awareness of disaster management strategies.

Variables	χ^2	df	P-value	Decision
Sex	0.143	1	0.612	Not Significant
Marital status	5.134	1	0.014	Significant
Level of education	17.678	5	0.001	Significant

Table 7 shows that there is no significant relationship between sex and awareness to disaster management strategies at ($p > 0.05$). This means that whether you are a male or female does not guarantee access to information on disaster management strategy. However, there is significant relationship between marital status (χ^2 =5.134; p = 0.014) and level of education ((χ^2 =17.678; p = 0.001), which means that marital status has influence on awareness to disaster management strategies.

Table 8 revealed no significant relationship between the awareness of all the respondents and selected training needs at $p > 0.05$. This was shown in the previous result on low awareness and high need for training by the respondents. It also means that whether the respondents are aware or not does not influence the desire for training.

Table 8: Chi-square statistics on the relationship between the respondents' awareness and selected training needs.

Variables	χ^2	df	P-value	Decision
Radio weather reading	2.552	1	0.281	Not significant
Training on flood prevent/control	1.006	1	0.901	Not significant
Erosion prevention/control	0.115	1	0.725	Not significant
Mobilize communities to take disaster preparedness	1.565	1	0.212	Not significant
Transferring the risk (Insurance)	0.119	1	0.650	Not significant
Proper land use management	0.123	1	734	Not significant
Pollution prevention and control	1.087	1	0.186	Not significant
Disease prevention/control/immunization	0.288	1	0.687	Not significant

4 Conclusion

Farmers are well aware of disaster risks but highly not aware of disaster management strategies in the study area. They face lots of challenges in risk reduction in the promotion of health, immunization, advocacy; mitigation in information, education, communication, insurance advocacy; preparedness in situation analysis, hazard mapping, contingency planning, early warning, education; during disaster management in drug distribution, personnel deployment and counselling. This is why they have high desire for training for all disaster risks in the area. It is more valuable to build more effective strategies for adapting to disaster risks better training will lead to efficient reduction and mitigation of disaster risks for sustainable food security and livelihoods.

5 Recommendations

Reduction and mitigation of disaster requires multi-disciplinary research and multi-institutional, participatory effort involving scientific, development and user communities. The guiding principles for disaster risk reduction strategies in Nigeria should be initiated and implemented, especially in the areas of poverty reduction, disaster prevention, capacity building of communities, partnership with the other tiers of government, education to increase public awareness and establishment of information networks. The enabling legislation for disaster risk management in Nigeria, such as the NEMA establishment Act should be amended to strengthen coordination of disaster management in order to be more efficient and effective. The new engagement in disaster management presupposes that states and local government councils across the country should take more proactive stance in the whole effort. Support to National Curriculum and Text Book Board (NCTB), public and private universities, and research institutes to strengthen the capacities to incorporate risk reduction issues in existing courses, degree programme and to introduce new courses and carry out research initiatives. Support to public and private training institutes and academics to strengthen the capacities to incorporate risk reduction in existing training programmes, courses. The following risk management strategies in agriculture could involve:

1. Avoiding the dangers,
2. Preventing/reducing the frequency of impacts,
3. Controlling/reducing the consequences (coping and adaptation measures),
4. Transferring the risk (e.g. insurance),
5. Responding appropriately to incidents/accidents (e.g. disaster management),
6. Recovering or rehabilitating as soon as possible (e.g. media response).

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