Disaster Assessment and Mitigation Planning:
A Humanitarian Logistics Based Approach

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ABSTRACT

This paper proposes a mathematical modeling-based approach for assessing disaster effects and selecting suitable mitigation alternatives to provide humanitarian relief (HR) supplies, shelter, rescue services, and long-term services after a disaster event. Mitigation steps, such as arrangement of shelter and providing HR items (food, water, medicine, etc.) are the immediate requirements after a disaster. Since governments and non-governmental organizations (NGOs) providing humanitarian aid need to know the requirements of relief supplies and resources for collecting relief supplies, organizing and initiating mitigation steps, a quick assessment of the requirements is the precondition for effective disaster management. Based on satellite images from weather forecasting channels, an area/dimension of the disaster-affected zones and the extent of the overall damage may often be obtained. The proposed approach then estimates the requirements for HR supplies, supporting resources, and rescue services using the census and other government data. It then determines reliable transportation routes, optimum collection and distribution centers, alternatives for resource support, rescue services, and long-term help needed for the disaster-affected zones. A numerical example illustrates the applicability of the model in disaster mitigation planning.

Keywords: Disaster Assessment, Humanitarian Relief Operations, Disaster Mitigation Alternatives, Mixed-Integer Programming

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1. INTRODUCTION

The increasing frequencies of natural disaster occurrences have made humanitarian logistics and disaster mitigation planning an important research area. Disaster occurrences and their impact on resources and human lives have been widely covered in the literature, news media, and publications from international organizations (ABC News, 2010; De Marchi, 2007; IFRC, 2011; Lees, 1996; Loayza et al., 2012; Magnone, 2012; Rodriguez et al., 2012; United Nations, 2008). Disaster management includes assessment of the vulnerabilities of a disaster-prone zone for planning preventive measures or mitigation preparation (Hochrainer and Mechler, 2011; Wei et al., 2004), assessment of the needs after the disaster (Chen et al., 2012; Leaning, 2008; Lillibrige et al., 1993), identification of logistical factors for mitigation planning (Nivolianitou and Synodinou, 2011), and coping with the disaster event for relief and rehabilitation of the affected population (Pomeroy et al., 2006). Other studies have focused on relief allocation strategies to ensure that the affected populations receive relief, es-
especially in developing countries (Morris and Wodon, 2003).

Past disaster events have highlighted the requirements of emergency rescue services, emergency medical needs, shelter and other resource supports in addition to relief supplies (e.g., food, medicine, and potable water) in the affected zones (Owens et al., 2005; van der Velden et al., 2012; Watt, 1977). It may be noted here that the emergency rescue services, medical needs, and shelters are to be provided in the immediate aftermath of the disaster. To ensure a timely response to the needs for emergency services (rescue assistance, medical supports, and shelter) and humanitarian relief (HR) supplies (food, medicine, potable water), the supporting organizations (government agencies, non-governmental organizations [NGOs], and private entities) need an assessment of the disaster effects just after the event, which constitutes the basis for procuring and organizing relief supplies and resources to be included in any mitigation plan. In the context of assessment, it may be noted that the effects of a disaster event change dynamically as time passes. In some cases (e.g., floods, droughts, volcanic eruptions, nuclear disasters) the effects of the disaster may continue for days or even weeks, prompting the authorities to rely on satellite images (broadcast by news media, government agencies, etc.) to conduct the assessment and to dynamically update it as time passes. This information combined with governmental data (such as census information, local economic data, etc.) may be used to arrive at an acceptable quality, first-hand assessment that may be refined later.

It is apparent that the service-providing organizations including government agencies will need information on the availability and reliability of transportation networks, and suitable distribution centers to be assigned to the affected zones to provide relief work and emergency services. Often supply centers that procure relief items and organize support activities may be spread over the country. Thus, the decision needs to be made to choose suitable supply and distribution centers, transportation modes, and the quantities to be sent to each affected zone considering the dynamically changing disaster situation and the transportation network condition.

An affected zone also requires emergency resource supports in terms of medical aid, shelter, and rescue services. Supporting organizations need to select suitable options in terms of cost, practical feasibility, and availability of emergency services to provide quick responses for providing such resource supports in addition to the amount of relief items.

Based on the extent of the damage caused by a disaster, there may be affected populations in select zones that would not be able to get back to their homes for a few months. In such situations, there is a need for extended-time rehabilitation help in the form of temporary schools for children, repairing or rebuilding the damaged homes, and other supports in order to get the affected population to resume their economic activities.

In view of the multiplicity of the assessment variables, response requirements, and the available options, a structured, mathematical modeling-based approach is suggested that would aid the supporting organizations in coming up with timely and appropriate decisions. There are a limited number of studies that comprehensively address disaster mitigation plans based on the assessment of appropriate requirements discussed above. This study is an attempt to bring into the picture an assessment and mitigation plan that recognizes the foreseeable effects of a disaster.

The remainder of the paper is organized in the following way. The next section includes literature survey. Section 3 develops the mathematical model and outlines the problem statement, assumptions, and the schematic network view of the problem, as well as the model and its description. Section 4 illustrates the model application using a numerical example, and Section 5 closes with some observations and conclusions.

2. LITERATURE SURVEY

In this section we present a review of the literature on: 1) emergency relief requirements, distribution and transportation networks; 2) rescue services in the event of a natural disaster; 3) resource requirements when disaster hits; 4) rehabilitation or long-term support requirements; and 5) planning and management of mitigation measures.

2.1 Emergency Relief Requirements, Distribution and Transportation Network

The literature on humanitarian emergency logistics planning is mostly focused on distribution and transportation of relief supplies. An overview of the issues involved in the transportation and routing of relief supplies may be found in the review study by de la Torre et al. (2012). Liberatore et al. (2012) proposed an emergency goods distribution model and illustrated its application to the Haiti earthquake disaster. In addition to addressing the optimum distribution network selection, the paper addressed a recovery plan for the damaged connection arcs of the network using predefined 0/1 reliability levels and set amounts of construction cost. Berkoune et al. (2012) proposed a model for transportation and delivery of relief items from a set of distribution centers to demand nodes. The model also determines the optimum number of trips and vehicle types. Lin et al. (2011) proposed a multi-item, multi-vehicle, and multi-period integer programming model for the delivery of emergency supplies after a disaster considering the unlimited capacity of a single supply depot to satisfy multiple demand nodes.
2.2 Rescue Services in the Event of Natural Disasters

Rescue services and the relevant planning-related problems are not well covered in the disaster management literature. Sheu (2010) proposed a model for estimating and dynamically updating the number of persons trapped, fatalities involved and the rescue relief requirements in earthquake-like disasters. Friedrich et al. (2000) proposed a similar dynamic model for optimal assignment of available resources for rescuing the earthquake-trapped population with the objective of minimizing fatalities. Auf der Heide (2006) recommended evidence-based rescue services planning based on the investigation of the data collected on-site just after the disaster.

2.3 Resource Requirements When Disaster Hits

Most of the literature on humanitarian logistics studied resource supports as a part of the general relief operations instead of considering it as a separate topic. In 1998 the U.S. government developed the National Disaster Medical System as an asset of the Federal Emergency Management Agency to provide state-of-the-art medical care to U.S. citizens living abroad, and to assist host countries, in the event of a disaster. It deploys with medical supplies, pharmaceuticals, surgical equipment, and a Deployable Rapid Assembly Shelter/Surgical Hospital (Owens et al., 2005). Such resources involve large investments and are usually out of reach for developing or under-developed countries. To reduce fatalities in earthquake disaster areas, Liu et al. (2011) proposed site selection approaches to build emergency shelters outside the earthquake vulnerable areas. This study offers an example of readiness planning for future disaster events. In a similar vein, Chen et al. (2011) proposed a disaster response framework and model for providing emergency civil engineering construction equipment support to disaster-hit urban areas. The proposed framework and integrated model includes geographic information system (GIS)-based information collection facilities that aid in allocating resources based on the requirements. Helicopters are an example of the emergency service resources that are used for population evacuation, transportation to shelters and hospitals, and for rescue operations in the event of a disaster. Considering these factors, Fenn et al. (1999) studied the assessment of preparedness planning for the U.S. Helicopter Emergency Medical Services in response to disasters.

2.4 Rehabilitation or Long-Term Support Requirements

Extended-time supports or rehabilitation supports are provided by the United Nations organizations (e.g., General Assembly, 2012), regional support centers (e.g., CONSRN, 2005), similar international organizations, and national governments. Pomeroy et al. (2006) studied past natural disasters including the Asian tsunami and proposed principles for rehabilitating coastal livelihoods. Literature also covers medical rehabilitation studies. Bathala (2005) conducted a case study at a walk-in clinic at a refugee relief camp in Krabi, Thailand. Based on the treatment and evaluation of more than 500 patients injured in the 2004 tsunami, the author reported that rehabilitation medicine was essential in the natural disaster relief work. Hashemi and Alesheikh (2011) proposed a model for assessment, mitigation and rehabilitation of building structures, roads, and highway networks damaged by earthquakes.

2.5 Planning and Management of Mitigation Measures

Using an empirical study based on the emergency response teams in Greece, Nivolianitou and Synodinou (2011) identified operational and logistical factors that facilitate emergency management of natural disasters and accidents. Examples of the factors identified include mobilization of emergency groups, early reaction time, information technology, and competence of the response team. Humanitarian logistics involves several parties including international donor agencies, local donors, NGOs and government agencies in addition to the entities involved in transportation, warehousing, and information services. Balcik et al. (2010) studied the coordination practices and challenges in relief works in disaster-affected zones. Based on their analysis and comparing the current situation with the commercial supply chains, the authors concluded that the current practices of collaborative procurement and third-party warehousing had been conducive to relief environment. Optimization models have been used by several researchers in disaster management and emergency logistics planning (e.g., see Caunhye et al., 2012). To obtain cost effective and real time solutions for mitigating disaster events, Altay and Green III (2006) suggested OR/MS-based disaster operations management approach as the most suitable method considering the randomness of the disaster impacts in addition to uniqueness of the demand dynamics.

The literature review reveals that the crucial disaster management factors are disaster assessment and relief operations to provide rescue services; transportation and distribution of HR items; providing resource support in terms of shelter and medical services; and planning for extended-time rehabilitations in select disaster cases. The literature also reveals that the disaster events in most cases need quick mitigation responses in terms of all the factors, not on just one or two. Table 1 shows the specific areas addressed and the methodologies used towards disaster mitigation by select literature.

It is apparent that there is no comprehensive disaster management approach in the literature that includes suitable criteria on the assessment of requirements and mitigation plan for HR items (food, water, and medicine),
Table 1. Disaster mitigation approaches studied in select literature

<table>
<thead>
<tr>
<th>Addressed area</th>
<th>Proposed mitigation</th>
<th>Methodology</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a), (b)</td>
<td>Risk pooling among cities, infrastructure and liquidity support</td>
<td>Investigation of resources in Asian cities and past risk events</td>
<td>Hochrainer and Mechler (2011)</td>
</tr>
<tr>
<td>(a), (b), (c)</td>
<td>Deployment and planning of resources for relief operation</td>
<td>Transportation model</td>
<td>Berkoune et al. (2012)</td>
</tr>
<tr>
<td>(a), (e)</td>
<td>Coordination of relief chains in pre and post disaster relief operation</td>
<td>Study of relief and commercial supply chain operation</td>
<td>Balci et al. (2010)</td>
</tr>
<tr>
<td>(c)</td>
<td>OR/MS approach for readiness, response, and disaster recovery</td>
<td>Review study</td>
<td>Altay and Green (2006)</td>
</tr>
<tr>
<td>(e)</td>
<td>Optimal assignment of available resources to reduce fatalities</td>
<td>Dynamic optimization model</td>
<td>Fiedrich et al. (2000)</td>
</tr>
<tr>
<td>(b)</td>
<td>Emergency health care resources deployment</td>
<td>Experience based response recommendation and planning</td>
<td>Owens et al. (2005)</td>
</tr>
<tr>
<td>(b), (e)</td>
<td>Evacuation of people and resources from disaster hit urban areas</td>
<td>Model based risk assessment evacuation planning</td>
<td>Chen et al. (2012)</td>
</tr>
<tr>
<td>(c)</td>
<td>Contribution of armed services in rescue, evacuation and others</td>
<td>Review of relevant lectures</td>
<td>Watt (1977)</td>
</tr>
<tr>
<td>(a), (b), (e)</td>
<td>Earthquake loss estimation for mitigation and aversion planning</td>
<td>Pre- and post-earthquake disaster assessment model</td>
<td>Hashemi and Alsheikh (2011)</td>
</tr>
<tr>
<td>(b), (c), (e)</td>
<td>Identification of factors for effective emergency management and intervention</td>
<td>Study of policies/protocols, and interviewing stakeholders in risk and emergencies</td>
<td>Nivolianitou and Synodinou (2011)</td>
</tr>
<tr>
<td>(a), (d), (e)</td>
<td>Distribution of relief items and quick recovery from disaster effects</td>
<td>Model for recovery of damaged distribution networks</td>
<td>Liberatore et al. (2011)</td>
</tr>
<tr>
<td>(a), (b), (e)</td>
<td>Data based DSS supports damage assessment and management</td>
<td>Decision support system (DSS) to disaster management</td>
<td>Rodriguez et al. (2012)</td>
</tr>
<tr>
<td>(b), (d), (e)</td>
<td>Allocation of construction equipment for disaster response operation</td>
<td>A decision model</td>
<td>Chen et al. (2011)</td>
</tr>
<tr>
<td>(a), (b), (d)</td>
<td>For designing interventions to long- and short-term vulnerabilities</td>
<td>Study of past lessons to draw recommendations</td>
<td>Pomeroy et al. (2006)</td>
</tr>
</tbody>
</table>

(a): emergency relief requirements, distribution and transportation network, includes risk assessment, (b): resources requirements (aversion and or mitigation), (c): rescue services, (d): rehabilitation, long and short term support, (e): planning and management of mitigation measures. OR/MS: operations research/management science.

Table 2. Humanitarian logistics planning framework

<table>
<thead>
<tr>
<th>Assessment of disaster effect</th>
<th>Estimation of relief items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basis information</strong></td>
<td>- Humanitarian relief (HR) items: Food, potable water, clothes, first aid medicine</td>
</tr>
<tr>
<td>- Satellite images of affected areas from weather channels</td>
<td><strong>Emergency resources</strong></td>
</tr>
<tr>
<td>- Area of the affected zone from state agency data</td>
<td>- Medical aid item: mobile/temporary hospitals, ambulances, physicians, nurses, and medicine.</td>
</tr>
<tr>
<td>- Data on population, housing, roads, building, and resources from state and census information</td>
<td>- Shelter: Temporary shelters (tents, building materials), possible relocation shelter to nearby cities, DCs</td>
</tr>
<tr>
<td>- Transportation network to affected zone for each mode with reliability</td>
<td>- Rescue services: Rescue equipment, transportation, helicopters, trained personnel</td>
</tr>
<tr>
<td>- Distribution centers (DC): Possible nearby city centers, and other facilities</td>
<td>- Utility resources: Temporary power, water and sewerage facilities</td>
</tr>
<tr>
<td>- Supply centers (SC): Locations for government agencies, non-governmental organizations, and other humanitarian organizations</td>
<td><strong>Logistics data for mitigation planning</strong></td>
</tr>
<tr>
<td>- Healthcare facilities</td>
<td><strong>Mitigation planning</strong></td>
</tr>
<tr>
<td>- Humanitarian relief (HR) items: Food, potable water, clothes, first aid medicine</td>
<td>- Transportation planning: HR items from SC to DCs</td>
</tr>
<tr>
<td>- Medical aid item: mobile/temporary hospitals, ambulances, physicians, nurses, and medicine.</td>
<td>- Distribution planning: HR items from DCs to affected demand zones</td>
</tr>
<tr>
<td>- Shelter: Temporary shelters (tents, building materials), possible relocation shelter to nearby cities, DCs</td>
<td>- Rescue services: Allocation of equipment, teams from DCs to affected demand zones</td>
</tr>
<tr>
<td>- Rescue services: Rescue equipment, transportation, helicopters, trained personnel</td>
<td>- Shelter: allocation of temporary shelters, planning on relocation options</td>
</tr>
<tr>
<td>- Utility resources: Temporary power, water and sewerage facilities</td>
<td>- Medical aid: allocation of teams, temporary facilities, relocation option to nearby city hospitals</td>
</tr>
<tr>
<td>- Extended time support: allocation of teams and resources in DCs to affected demand zones.</td>
<td></td>
</tr>
</tbody>
</table>
resources for emergency services (rescue, shelter, medical) and extended-time support or rehabilitation plan for disaster-affected population. This study is an attempt to fill that gap.

3. DISASTER ASSESSMENT AND MITIGATION MODEL

This section includes the problem statement, a humanitarian logistics planning framework for disaster mitigation, and the mathematical model formulation.

3.1 Problem Statement

We assume that a set of areas $N^d$ (demand nodes, or zones) of a country is struck by flood or cyclone, affecting a set of resources $B$ including homes, hospitals, schools, power supply, and municipal water supply lines (either due to flood water flows, or the river overflow in case of the cyclone). The communication networks connecting the demand nodes with the rest of the country are also affected. Let $N^s$ be the set of supply nodes where disaster relief agencies (governmental, NGOs, etc.) are located, and where they collect HR items, organize temporary shelters or shelter construction materials, and other resources from donor agencies (foreign or local) for disaster mitigation activities. Quick assessment of the relief and resource requirements will enable both the government agencies and the NGOs to take timely steps for collecting the required amounts of relief materials. The objectives of the study are to assess the disaster effect, estimate requirements for relief supplies, resources, and support services; evaluate the communication networks in the affected areas; and develop a mitigation plan for sending relief items from optimally-located supply nodes, and for providing resource supports considering various alternatives. The problem statement also includes the following assumptions:

1) Sufficient relief items and resources (for emergency support, rescue services, and extended time services) have been procured from the donor services and markets. As such there will be no shortages of the relief items and resources for supplying to the demand nodes.

2) Cost of relief items, resources, transportation, repair, restoration, and services (rescue, extended-time support, and emergency support and medical treatment) are known and will not change during the entire mitigation time horizon.

3) Sufficient and required number of trained service personnel, transports, equipment, and other resources are organized by the relief team.

4) Position of distribution nodes, transit nodes, transportation routes, and demand nodes have been decided based on maps and GIS data.

5) The monitoring cells have the required expertise and resources to track the routes, weather condition, and disaster effects at the demand nodes.

6) Data on affected population, per person HR and other relief requirements are available.

3.2 The Model Formulation

In this sub-section we first define the notations and then present the mathematical model.

3.2.1 Notations

Indices

- $B$ the set of immediately needed resources, $b \in B$
- $G$ the set of extended-time rehabilitation resources/supports for long-term disaster mitigation, $g \in G$
- $E$ the set of emergency rescue services, $e \in E$ (needed for rescuing people trapped in flooded areas, under debris in earthquake situations, etc.); $e = 1$, trained rescue teams; $e = 2$, motorized boats/helicopters, ambulances; $e = 3$, others
- $I$ the set of HR items, such as drinking water, food, medicine, $i \in I$
- $M$ the set of transportation modes (highways, railways, water ways, mixed modes, air) for connecting supply nodes to demand nodes, $m \in M$
- $N$ a set of nodes (demand zones, destinations/supply centers, indexed by $n \in N$ and $n' \in N^d$
- $N^d$ a set of demand nodes, $n \in N^d$, $n' \in N^d$
- $N^s$ a set of supply nodes, $n \in N^s$, $n' \in N^s$
- $N^o$ a set of distribution center (DC) nodes, $n \in N^o$, $n' \in N^o$
- $N^t$ a set of transit nodes along the communication network $n \in N^t$, $n' \in N^t$

$N^M$ be the partition of $N$ consisting of the set of HR item

- $O$ set of options, $o \in O$ for organizing immediate resources, for example, relevant to shelter; option $o = 1$ construction of temporary shelter (tents, big sheds, etc.); $o = 2$ moving the affected population to a safe, already built shelter (outside the vulnerable area, perhaps in a different state or city) using ships, airways, and other transports as feasible. Similarly for hospitals, option $o = 1$ means taking mobile hospital vans, wagons, and ships to the affected area; $o = 2$ means moving the affected population to hospitals in a nearby state or city using suitable transportation.

- $T$ time periods; each period $t$ is 1 day, $t \in T$

Parameters

- $BN$ : a large positive number
- $CA_{w_m}^n$ : cost of maintaining an alternative route from $n \in N$ to $n' \in N$ for transportation mode $m$ in period $t$
- $CAM_{w_m}^n$ : capacity of transportation mode $m$ to carry HR item $i$
- $CAW_{w_m}^n$ : capacity of DC node $n \in N^o$ for HR item $i$ in period $t$
- $CD_{w_m}^n$ : per-unit cost of distributing HR items from DC node $n \in N^o$ to demand node $n' \in N^d$
- $CE_e$ : per-family cost of emergency rescue service $e$
\( CH_{nt} \) : cost of maintaining an existing route from \( n \in N \) to \( n' \in N \) for transportation mode \( m \) in period \( t \)

\( CP_i \) : per-unit cost of purchasing HR items \( i \) in period \( t \)

\( CPL_{nt} \) : cost of selecting air transportation mode \( m \) from \( n \in N \) to \( n' \in N \) in period \( t \)

\( CPS_{en} \) : capacity of demand node \( n \) to provide a unit of emergency rescue service \( e \)

\( CPX_{gn} \) : capacity of DC node \( n \in N^w \) to provide extended-time rehabilitation resource \( g \) to a demand node

\( CR_{hot} \) : cost of providing immediate resource \( b \) under option \( o \) in period \( t \)

\( CS_{in} \) : capacity of the supply node \( n \in N^c \) to accommodate HR item \( i \)

\( CT_{in} \) : per-unit cost of transporting HR items using transportation mode \( m \) from node \( n \in N \) to \( n' \in N \)

\( CX_g \) : per-family cost of extended-time rehabilitation resource \( g \)

\( dx_{nt}, dex_{nt}, del_{nt} \) : 0/1 parameters set by the central disaster monitoring cell to decide on the applicability of extended-time rehabilitation resources, rescue services and immediate resource requirements, respectively, at demand node \( n \in N^d \)

\( EQ_e \) : equivalent number of families that rescue service \( e \) can accommodate

\( ER_{ext} \) : estimated number of families that need emergency rescue service \( e \) at demand node \( n \in N^d \) in period \( t \) based on media reports

\( ESX_{gn} \) : estimated number of families that need extended-time rehabilitation resource \( g \) (e.g., schools, medical support, shelters) at demand node \( n \in N^d \)

\( FB_{bno} \) : fixed cost of option \( o \) to provide immediate resource \( b \) at demand node \( n \in N^d \)

\( FES_{en} \) : fixed cost of providing emergency rescue service \( e \) from DC node \( n \in N^w \)

\( FK_n \) : fixed cost of opening transit node \( n \in N^t \)

\( FM_{mt} \) : fixed cost of using transportation mode \( m \)

\( FN_{nn} \) : fixed cost of opening supply node \( n \in N^d \)

\( FS_n \) : average family size at demand node \( n \in N^d \) based on census data

\( FW_n \) : fixed cost of opening DC node \( n \in N^w \)

\( FX_{gn} \) : fixed cost of providing extended-time rehabilitation resource \( g \) from DC node \( n \in N^w \)

\( P_n \) : population size at demand node \( n \in N^d \) based on area map and census data

\( PER_{en} \) : percentage of families that need emergency rescue service \( e \) at demand node \( n \in N^d \) based on media/satellite scan-based reports on extent of damage

\( PR_{bno} \) : percentage of families that need resource \( b \) at demand node \( n \in N^d \) based on media/satellite scan-based reports on the extent of damage

\( PXR_{gn} \) : estimated percentage of families that need extended time rehabilitation resource \( g \) at demand node \( n \in N^d \) based on media/satellite scan-based reports on the extent of damage

\( R_{hot} \) : estimated number of families that need immediate resource \( b \) at demand node \( n \in N^d \) according to inspection/survey in period \( t \)

\( RAc_{nt} \) : a 0/1 parameter indicating the reliability status of transportation mode \( m \) on the alternative route from \( n \) to \( n' \) in period \( t \) as set by the monitoring cell

\( ROc_{nt} \) : a 0/1 parameter indicating the reliability status of transportation mode \( m \) on the existing route from \( n \) to \( n' \) in period \( t \) as set by the monitoring cell

\( RPL_{nt} \) : a 0/1 parameter indicating the reliability status of air transportation mode \( m \) from \( n \) to \( n' \) in period \( t \) based on the severity of the disaster

\( TSU_t \) : total requirements of HR item \( i \) in period \( t \)

\( U_{in} \) : estimated per-family requirements of HR item \( i \) at demand node \( n \in N^d \)

\( Variables \)

\( a_{nt} \) = 1 if DC node \( n \in N^w \) is assigned to demand node \( n' \in N^d \); 0, otherwise

\( c_m \) = 1 if transportation mode \( m \) is selected; 0, otherwise

\( dx_{nt} \) = 1 if DC node \( n \in N^w \) is operating to provide extended-time rehabilitation resources; 0, otherwise

\( ex_{og} \) = units of extended-time rehabilitation resource \( g \) supplied to demand node \( n \in N^d \) from DC node \( n' \in N^w \)

\( f_{in} \) : quantity of HR item \( i \) moving along the route \( n \in N^d \) to \( n' \in N^d \) using transportation mode \( m \) in period \( t \)

\( h_n \) = 1 if DC node \( n \in N^w \) is open; 0, otherwise

\( h_{es} \) = 1 if DC node \( n \in N^w \) is operating to provide rescue services; 0, otherwise

\( k_m \) = 1 if transit node \( n \in N^t \) is open; 0, otherwise

\( k_{bno} \) = 1 if demand node \( n \in N^d \) is supplied extended-time resource \( b \) from DC node \( n \in N^d \); 0, otherwise

\( mr_{bno} \) : requirements of immediate resource \( b \) at demand node \( n \in N^d \) under option \( o \) in period \( t \)

\( q_{in} \) : estimated requirements of HR item \( i \) in period \( t \) at demand node \( n \in N^d \)

\( r_{nt} \) = 1 if the alternative route from \( n \in N \) to \( n' \in N \) is deemed reliable in period \( t \) using transportation mode \( m \); 0, otherwise

\( r_{nt} \) = 1 if existing route from \( n \in N \) to \( n' \in N \) is deemed reliable in period \( t \) using transportation mode \( m \); 0, otherwise

\( rpl_{nt} \) = 1 if existing and alternative routes for other modes are unavailable and air transportation mode \( m \) from \( n \in N \) to \( n' \in N \) is selected in pe-
period $t$, 0, otherwise

$s_{cont}^n$: units of emergency rescue service $e$ provided at demand node $n \in N^d$ from DC node $n' \in N^d$ in period $t$

$s_{out}^n$: supply of HR item $t$ at supply node $n \in N$, collected/received from outside, in period $t$

$u_{bno}^{nb} = 1$ if option $n$ is chosen for resource requirement $b$ at demand node $n' \in N^d$; 0, otherwise

$v_n = 1$ if supply node $n \in N$ is open; 0, otherwise

$w_{n'n} = 1$ if emergency rescue service is provided at demand node $n \in N^d$ from DC node $n' \in N^d$; 0, otherwise

$y_{in}\tau$: quantity of HR item $i$ to be distributed from DC node $n \in N^d$ to demand node $n' \in N^d$ in period $t$

### The Mathematical Model

The objective function is to minimize the **Total cost**, where:

\[
\text{Total cost} = CHR + CTH + CMHR + CIR + CRS + CXT (1)
\]

The cost items for Eq. (1) are described below in Eq. (1.1) to (1.6):

\[
CHR = \sum_{i \in N} \sum_{t \in T} CP_i \sum_{n \in N^d} y_{in}\tau + \sum_{n \in N} v_n FN_n (1.1)
\]

Eq. (1.1) computes $CHR$, the procurement and fixed cost of HR items.

\[
CTH = \sum_{n \in N^d} \sum_{m \in M} \sum_{e \in E} CT_{ne} \sum_{i \in N} f_{in}\tau + \sum_{i \in N} c_{e} FM_e + \sum_{i \in N} k_FK_e (1.2)
\]

\[+ \sum_{n \in N^d} \sum_{m \in M} \sum_{e \in E} CD_{ne} \sum_{i \in N} y_{in}\tau + \sum_{n \in N} h_FW_n (1.2)
\]

Eq. (1.2) computes $CTH$, the cost of transporting HR items from supply nodes to DC nodes and distributing them to demand nodes, the fixed cost of keeping the distribution nodes and transit nodes open, and the fixed cost of selecting a transportation mode.

\[
CMHR = \sum_{n \in N^d} \sum_{m \in M} \sum_{e \in E} r_{ne}^{m'} CA_{m'}^{n'} + \sum_{n \in N^d} \sum_{m \in M} \sum_{e \in E} r_{ne}^{m'} CH_{m'}^{n'} (1.3)
\]

\[+ \sum_{n \in N^d} \sum_{m \in M} \sum_{e \in E} r_{ne}^{m'} CPI_{m'}^{n'} (1.3)
\]

Eq. (1.3) computes $CMHR$, the cost of maintaining the roads, highways, waterways, and airways in reliable conditions for the transportation modes used to send HR items to demand nodes.

\[
CRR = \sum_{b \in B} \sum_{n \in N^d} u_{bno}^{nb} FB_{bno} + \sum_{b \in B} \sum_{n \in N^d} \sum_{t \in T} mr_{bno} CRR_{bno} (1.4)
\]

Eq. (1.4) computes $CRR$, the cost of providing immediately-required resources considering the fixed cost of selecting the options and the overall cost of providing the resources under that option.

\[
CRS = \sum_{e \in E} \sum_{n \in N} \sum_{n \in N^d} \sum_{t \in T} s_{e}^{n'} + \sum_{e \in E} \sum_{n \in N^d} h_FSES (1.5)
\]

Eq. (1.5) computes $CRS$, the cost of providing emergency rescue services from a DC node to the demand node, and the fixed cost of providing the service at the DC node.

\[
CXT = \sum_{g \in G} \sum_{n \in N^d} \sum_{n \in N^d} \sum_{t \in T} \sum_{n \in N^d} d_{x}^{n'} FX_{x} (1.6)
\]

Eq. (1.6) computes $CXT$, the cost of providing extended-time rehabilitation resources from a DC node to a demand node and the fixed cost of providing the service at the DC node.

The constraints are as follows.

\[
TSU_{y} = \sum_{i \in I} \left[ \frac{P_{n}}{FS_{n}} \right] \forall i \in I, t (2)
\]

Constraint (2) accumulates the total amounts of the HR item requirements in each period at all the demand nodes.

\[
\sum_{n \in N^d} y_{in}\tau \leq q_{in}\tau \forall i, n \in N^d, t (3)
\]

Constraint (3) balances the HR item shipments from DC nodes against the requirements at the demand nodes.

\[
y_{in}\tau \leq a_{in}\tau q_{in}\tau \forall i, n \in N^d, n' \in N^d, t (4)
\]

The above constraint assigns DC nodes to demand nodes to address the requirements effectively.

\[
\sum_{i \in I} y_{in}\tau \leq h_{i} CA_{in} \forall i, n \in N^d, t (5)
\]

Constraint (5) limits the shipments of an HR item from a DC node based on its capacity.

\[
a_{in} \leq h_{i} \forall n \in N^d, n' \in N^d (6)
\]

Constraint (6) ensures that a DC node is open before it is assigned to a demand node.
Constraint (7) balances the flow of HR items to and from DC nodes.

\[ f_{n i}^m \leq c_m CAM_i^n S_i \quad \forall i, n \in N, n' \in N, t, m \quad (8) \]

Constraint (8) limits the flow through a route based on the capacity of the transport mode selected.

\[ s_{u n} \leq v_i CS_n \quad \forall i, n \in N^c, t \quad (9) \]

Constraint (9) limits the shipments of HR items from a supply node based on its capacity to store the items.

\[ \sum_{n \in N^c} s_{u n} = TSU_n \quad \forall i, t \quad (10) \]

Constraint (10) balances the total shipments of an HR item out of all the supply nodes in a period against the total requirements of that item in the same period.

\[ s_{u n} + \sum_{e \in E} \sum_{n' \in N^c} f_{w n' n} = \sum_{n' \in N^c} f_{w n' t} \quad \forall i, n \in N^c, t \quad (11) \]

Constraint (11) is a balance equation that keeps track of all the flows into and out of a supply node.

\[ \sum_{n' \in N^c} f_{w n' n} = \sum_{n' \in N^c} f_{n' t} \quad \forall i, n \in N^c, t \quad (12) \]

Eq. (12) balances the inflow with the outflow for the transit node that does not have an inflow from outside sources.

\[ F_{n t}^n \leq (r_{n t}^m + r_2a_{n t}^m + r_3p_{n t}^m) CAM_i^n \quad \forall i, n \in N, n' \in N, t, m \quad (13) \]

Constraint (13) ensures a feasible flow through a route, considering the reliability of the original, alternative, or special air routes. This constraint acts in combination with constraints (14) and (15).

\[ r_{n t}^m + r_2a_{n t}^m + r_3p_{n t}^m \leq 1 \quad \forall n \in N, n' \in N, t, m \quad (14) \]

Constraint (14) selects at most one reliable route for supplying the HR items.

\[ r_{n t}^m \leq R_{n t}^m, r_2a_{n t}^m \leq R_2a_{n t}^m, r_3p_{n t}^m \leq R_3p_{n t}^m \quad \forall i, n \in N, n' \in N, t, m \quad (15) \]

Constraint (15) facilitates the selection of the original, alternative, or air route if they are reliable.

\[ f_{n i}^m \leq k_i BN \quad \forall i, n \in N^c, n' \in N, t, m \quad (16) \]

Constraint (16) ensures the opening of a transit node before any flows go through it.

\[ m r_{n o a}^m \leq u_{n o} [d_{e n} P_{f S_n}^a P_{R o a}^n] \quad \forall b \in B, n \in N^c, a \in O, t \quad (17) \]

Based on the decision of the disaster monitoring cell (through the 0/1 parameter delbn), constraint (17) estimates the requirements of the immediately-required resources at the demand nodes, and selects a feasible option for providing them.

\[ \sum_{a \in O} u_{a n} = 1 \quad \forall b, n \in N^c, a \in O \quad (18) \]

Constraint (18) ensures that only one option is chosen for this purpose.

\[ s_{e n}^m \geq w_s [d_{e n} P_{f S_n}^a P_{R e s}^n] \quad \forall e \in E, n' \in N^c, n \in N^d, t \quad (19) \]

Based on the confirmation of the applicability by the disaster monitoring cell (through the 0/1 parameter desen), constraint (19) estimates the emergency rescue service requirements at demand nodes, and selects suitable DC nodes to provide the services.

\[ s_{e n} \leq h_{e n} C P_{S n} E_{Q} \quad \forall e \in E, n' \in N^c, n \in N^d, t \quad (20) \]

Constraint (20) limits the rescue services within the capacity of the DC nodes to provide such services.

\[ w_{s n} \leq h_{es n} \quad \forall n \in N^c, n' \in N^d \quad (21) \]

Constraint (21) ensures that a DC node is open before it can provide rescue services to demand nodes.

\[ E_{X n} \leq l_{e n} [d_{e n} P_{f S_n}^a P_{X R_{n e}}] \quad \forall g \in G, n \in N^d, n' \in N^e \quad (22) \]

Constraint (22) estimates the extended-time rehabilitation resource supports for the demand nodes based on the application of such services as decided by the disaster monitoring cell (though the 0/1 parameter dxe), and assigns suitable DC nodes to provide the resources.

\[ E_{X n} \leq d_{e n} C P_{n e} X R_{g e} \quad \forall g \in G, n \in N^d n' \in N^d \quad (23) \]

Constraint (23) limits the shipments of extended time resources at a DC node within its capacity to pro-
disaster situations are complex. It may be mentioned here that the mitigation issues for a
the approach of optimizing the service level. However, selecting mitigation issues in the model, we have not taken
may not be able to bear. Considering the inclusion of
costs to the relief agencies, which in most cases they
Moreover, maximizing the service level implies higher
restoring power supplies and other utility services, etc.
veral other services and supports including the repair of
roads and bridges, restoring the ecological conditions,
items, emergency resources, rescue services, and ex-
mand nodes, and the general estimation basis for re-
habilitation support at the demand nodes.

4. A NUMERICAL EXAMPLE

A numerical example that closely resembles the situation faced by a flood-prone Asian country is illustrated here. In this scenario, 17 southern low-land districts of the country are badly affected by a recent flood. The demand zones/districts are supplied from 13 centers nearby (the DC nodes) that receive relief aid from 6 supply centers (the supply nodes) located at various parts of the country. The 6 supply nodes are connected to the DC nodes via a transportation network of highways, railways, waterways, and air routes. The network consists of 30 nodes that include the 6 supply nodes (nodes 1, 2, ..., 6), the 13 DC nodes (18, 19, ..., 30), and the remaining 11 nodes which work as transit nodes for connecting the highways, railways, waterways, and mixed mode transports routes. The demand nodes are supplied with HR items through designated DC nodes.

The distribution network diagram in Figure 1 presents the connecting communication arcs in terms of the applicable transportation modes (railway, highway, water ways, and air routes), and schematic positions of the supply nodes (1 to 6), the DC nodes (18 to 30), and the demand nodes (1 to 17). The suitability of the communication arcs for the various transportation modes are dynamically updated in each period using a 0–1 reliability parameter based on status reports communicated by the disaster monitoring cell operated by government agencies. If an existing arc connecting two nodes fails, alternative arcs through highway and waterway modes are available. When both the existing and alternative routes for transporting HR items become unavailable, the proposed model tries to generate different routes (i.e., arc combinations in mixed modes) or allocate air transportation modes.

Table 3 presents the estimated requirements of a typical relief operation for supplying HR items to 5 demand nodes, and the general estimation basis for resource support, rescue services, and extended-time rehabilitation support at the demand nodes.

This estimation is based on the extent of the disaster as reported by the disaster monitoring cell and the data available through census reports and national statistical data bases on family size, and the assumed average requirements per family. Input data on cost figures, per family requirements, population figures, transportation times and others are randomly generated considering data ranges in similar practical disaster situations.

The requirement estimates for emergency services and resource supports are in terms of the number of families of average size, and the HR item estimates are per family, in order to generalize the cost computations at different times, locations and prices. Table 3 includes the typical basic inputs to the model relevant to demand nodes. Other input data, such as the road reliability variables (obtained from the national monitoring cell dynamically, period to period), capacities of standard transport modes, and the procurement, transportation and distribution costs are not included to save space.

The model was solved for the example problem using LINGO 9 on a standard PC in approximately 5 minutes. The solution involved 21,651 variables in total, including 9,383 integer variables, and 19,757 constraints.

Table 4 presents the typical model output on the flow of HR item 1 (food packets for adults) in period 1 to DC nodes using reliable routes and suitable transportation modes in the network (Figure 1). It also shows the
Table 3A. The estimated requirements of a typical relief operation for supplying HR items to 5 demand nodes

<table>
<thead>
<tr>
<th>Demand node</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of families</td>
<td>226,200</td>
<td>295,700</td>
<td>796,200</td>
<td>1,848,800</td>
<td>655,800</td>
</tr>
<tr>
<td>Families that need HR items (%)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7-day requirements/family</td>
<td>Family size U(3, 7), Adults U(3, 4)/family, Children U(2, 3)/family</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food for adults (packets)</td>
<td>22</td>
<td>27</td>
<td>21</td>
<td>28</td>
<td>21</td>
</tr>
<tr>
<td>Food for children (packets)</td>
<td>18</td>
<td>15</td>
<td>19</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Water</td>
<td>42</td>
<td>21</td>
<td>25</td>
<td>49</td>
<td>35</td>
</tr>
<tr>
<td>Medicine</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

U: estimated per-family requirements of HR item at demand node based on a uniform distribution.

Table 3B. General estimation basis for computing rescue services, resource support and extended time services at a demand node

<table>
<thead>
<tr>
<th>Fixed cost ($)</th>
<th>Cost/family ($)</th>
<th>Capability of covering in one period (no. of families)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rescue service</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rescue team</td>
<td>2,000</td>
<td>U (250, 350)</td>
</tr>
<tr>
<td>Helicopter</td>
<td>35,000</td>
<td>U (300, 400)</td>
</tr>
<tr>
<td>Engine boat</td>
<td>10,000</td>
<td>U (200, 300)</td>
</tr>
<tr>
<td>Resource support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option 1</td>
<td>10,000</td>
<td>U (150, 250)</td>
</tr>
<tr>
<td>Option 2</td>
<td>1,500</td>
<td>U (250, 350)</td>
</tr>
<tr>
<td>Option 3</td>
<td>20,000</td>
<td>U (50, 100)</td>
</tr>
<tr>
<td>Hospital service</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option 1</td>
<td>40,000</td>
<td>U (400, 600)</td>
</tr>
<tr>
<td>Option 2</td>
<td>75,000</td>
<td>U (150, 205)</td>
</tr>
<tr>
<td>Option 3</td>
<td>20,000</td>
<td>U (200, 400)</td>
</tr>
<tr>
<td>Others (e.g., power source)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option 1</td>
<td>5,000</td>
<td>U (50, 150)</td>
</tr>
<tr>
<td>Option 2</td>
<td>50,000</td>
<td>U (15, 30)</td>
</tr>
<tr>
<td>Option 3</td>
<td>20,000</td>
<td>U (30, 50)</td>
</tr>
<tr>
<td>Extended-time service</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schools for children</td>
<td>20,000</td>
<td>40</td>
</tr>
<tr>
<td>Home repair/rebuilding</td>
<td>5,000</td>
<td>50</td>
</tr>
<tr>
<td>Cloth/medical support</td>
<td>5,000</td>
<td>500</td>
</tr>
</tbody>
</table>

U: estimated per-family requirements of HR item at demand node based on a uniform distribution.

d) Required by U (0.0075%, 0.01%) of families; applicable in periods 1 and 2.

b) Required by U (0.1%, 0.15%) of families; applicable in all periods.

c) Required by U (0.005% to 0.008%) of families; applicable in general.

d) One school per 300 families.

distribution of the item from DC nodes to demand nodes. For example, using highway transport (trucks), 79,832 units of the item are directly shipped from supply node 1 to DC node 18 (via route 1–18; Figure 1), which are finally distributed to demand node 2 (via route 18–2; Figure 1). HR items are often transported to DC nodes
through transit nodes when economically suitable and reliable direct routes to DC nodes are not available. To illustrate, using railway, highway and mixed transport modes, supply nodes 2, 3, and 4 shipped to transit node 13 (via routes 2–13, 3–13, 4–13), respectively, 375,000, 19,311, and 141,587 units for a total of 535,898 units at
node 13. From node 13, 166,787 units are shipped to node 23 (via route 13–23) and 369,111 units to node 25 (via route 13–25). The DC nodes 23 and 25 finally distributed the items to various demand nodes as may be observed in Table 4.

Table 5 presents the model output on the assessment of HR item requirements and their optimum supply locations for procurement and storage. The results are presented for period 1 only. The assessment procedure will be the same for the other two periods. For example, the model decided to procure a total of 3,081,362 units of HR item 1 for period 1 of which 79,832 units are to be stored at supply node 1; 591,970 units to be stored at supply node 2, etc.

Table 6 presents the typical model output on assessment of the requirements of emergency resource supports (such as shelter, hospital services, and other resources, e.g., power sources). For example, 444 families at demand node 2 needed shelter immediately, and the cost-effective option selected by the model is to move the families to an already available shelter in a nearby state, or to a safe location nearby.

Table 7 presents the typical model outcome on the assessment of rescue services needed at the affected demand nodes. For example, demand node 1 needs emergency rescue services by a trained rescue team for 25

---

**Table 5.** Assessment of humanitarian relief (HR) item requirements and their storage locations in period 1

<table>
<thead>
<tr>
<th>HR item</th>
<th>Supply node</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>79,832</td>
<td>591,970</td>
<td>597,037</td>
<td>516,587</td>
<td>595,936</td>
<td>700,000</td>
<td>3,081,362</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>47,637</td>
<td>428,470</td>
<td>418,590</td>
<td>420,780</td>
<td>430,206</td>
<td>440,000</td>
<td>2,185,683</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>148,978</td>
<td>845,000</td>
<td>838,956</td>
<td>833,681</td>
<td>840,648</td>
<td>858,182</td>
<td>4,365,445</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2,957</td>
<td>25,360</td>
<td>25,000</td>
<td>19,540</td>
<td>27,651</td>
<td>24,780</td>
<td>125,288</td>
</tr>
</tbody>
</table>

**Table 6.** Typical model output on assessment of emergency resource requirements by the affected demand nodes

<table>
<thead>
<tr>
<th>Demand node</th>
<th>Resource type</th>
<th>Option selected by model</th>
<th>Needed by no. of families</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Shelter</td>
<td>3 (moving to a safe city or location)</td>
<td>444</td>
</tr>
<tr>
<td>4</td>
<td>Other services</td>
<td>2 (repair existing power and utility facilities)</td>
<td>2,588</td>
</tr>
<tr>
<td>5</td>
<td>Hospital</td>
<td>2 (repair existing hospitals)</td>
<td>918</td>
</tr>
<tr>
<td>12</td>
<td>Shelter</td>
<td>3 (moving to a safe city or location)</td>
<td>1,179</td>
</tr>
<tr>
<td>14</td>
<td>Hospital</td>
<td>2 (repair existing hospitals)</td>
<td>1,179</td>
</tr>
<tr>
<td>15</td>
<td>Other services</td>
<td>2 (repair existing power and utility facilities)</td>
<td>547</td>
</tr>
<tr>
<td>16</td>
<td>Shelter</td>
<td>3 (moving to a safe city or location)</td>
<td>1,027</td>
</tr>
<tr>
<td>16</td>
<td>Hospital</td>
<td>2 (repair existing hospitals)</td>
<td>1,027</td>
</tr>
</tbody>
</table>

**Table 7.** Typical model output on assessment of emergency rescue service requirements by the affected demand nodes

<table>
<thead>
<tr>
<th>Demand node</th>
<th>Rescue service</th>
<th>Provided by DC</th>
<th>No. of families needing rescue service</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 (trained rescue team help)</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>3 (rescue by boat and other logistics)</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>3 (rescue by boat and other logistics)</td>
<td>20</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>3 (rescue by boat and other logistics)</td>
<td>20</td>
<td>87</td>
</tr>
<tr>
<td>10</td>
<td>1 (trained rescue team help)</td>
<td>25</td>
<td>27</td>
</tr>
<tr>
<td>12</td>
<td>1 (trained rescue team help)</td>
<td>28</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>2 (helicopter rescue)</td>
<td>25</td>
<td>105</td>
</tr>
<tr>
<td>14</td>
<td>2 (helicopter rescue)</td>
<td>28</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>3 (rescue by boat and other logistics)</td>
<td>28</td>
<td>52</td>
</tr>
<tr>
<td>15</td>
<td>1 (trained rescue team help)</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>2 (helicopter rescue)</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>3 (rescue by boat and other logistics)</td>
<td>28</td>
<td>52</td>
</tr>
<tr>
<td>17</td>
<td>1 (trained rescue team help)</td>
<td>28</td>
<td>100</td>
</tr>
</tbody>
</table>

DC: distribution center.
families, which are provided from DC node 20. As may be observed in Table 7, the disaster monitoring cell deployed the rescue service resources at three DC nodes, 20, 25, and 28, in order to provide the 3 types of services to demand nodes.

Table 8 describes the typical model output on assessment of the extended-time support requirements by the affected demand nodes. The long-term support responsibilities are assigned to five DC nodes (20, 21, 23, 27, and 28) to monitor the support activities. To illustrate, demand node 3 needed extended-time support in terms of schools for children for 69 families, which has been supported from DC node 20. Based on the previous discussion, this type of extended-time support is provided by international and government organizations to ensure resource availability and the required monitoring.

Based on the discussion of the model output, it is apparent that the model is capable of assessing several crucial disaster relief requirements based on information about the extent of the disaster, as reported by the disaster monitoring cell, and the data available through census reports and national statistical data bases on family size, and the assumed average requirements per family.

5. CONCLUSIONS

The research introduced an integer linear programming model-based systematic procedure for assessment of emergency relief requirements in disaster affected areas using readily available government data, national media reports or similar data from satellite scanning on the extent of the damage just after a disaster occurs. Such assessment is crucial for extending emergency rescue services, sending HR items, such as food, water, and emergency medicines to the affected population of the disaster-hit areas. In addition, the assessment will create the basis for procuring relief items from international and national donor agencies as well as government organizations.

In addition to the assessment, the proposed model includes an effective mitigation plan covering optimum routing and distribution of HR items considering network link reliability, capacity of transportation modes and the optimum location of the supply, transit, and DC nodes. The model also facilitates the designation of select DC nodes for providing emergency resource supports, rescue services and extended-time support services to the affected demand zones. To identify such affected zones, the model relies on input from national disaster monitoring cells based on their on-site investigations. The model generates a plan for the deployment of the required resources to the assigned DC nodes based on its assessment of the HR item requirements at the demand nodes.

The model includes a provision for updating the

<table>
<thead>
<tr>
<th>Demand node</th>
<th>Long-term support</th>
<th>Provided from DC</th>
<th>No. of families needing support</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1 (school for children)</td>
<td>20</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>2 (home repair or rebuilding help)</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>3 (clothes and medical support)</td>
<td>20</td>
<td>71</td>
</tr>
<tr>
<td>4</td>
<td>1 (school for children)</td>
<td>20 and 21</td>
<td>64 + 85 = 149</td>
</tr>
<tr>
<td></td>
<td>2 (home repair or rebuilding help)</td>
<td>20</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td>3 (clothes and medical support)</td>
<td>20</td>
<td>176</td>
</tr>
<tr>
<td>5</td>
<td>1 (school for children)</td>
<td>20</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>2 (home repair or rebuilding help)</td>
<td>20</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>3 (clothes and medical support)</td>
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<td>64</td>
</tr>
<tr>
<td>6</td>
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<td>21 and 23</td>
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</tr>
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<td>2 (home repair or rebuilding help)</td>
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<tr>
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<td>3 (clothes and medical support)</td>
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<td>1 (school for children)</td>
<td>27 and 28</td>
<td>5 + 38 = 43</td>
</tr>
<tr>
<td>17</td>
<td>1 (school for children)</td>
<td>28</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>2 (home repair or rebuilding help)</td>
<td>28</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>3 (clothes and medical support)</td>
<td>28</td>
<td>88</td>
</tr>
</tbody>
</table>

DC: distribution center.
disaster damage assessment and mitigation plan dynamically as time passes. The model may be used in preparing assessment and mitigation plans for several disaster-affected zones together, employing multiple supply, transit, and DC nodes and route networks.

REFERENCES


Bathala, B. S. (2005), The role of physical medicine and rehabilitation after an acute disaster situation: a case report, Archives of Physical Medicine and Rehabilitation, 86(9), e31.


De Marchi, B. (2007), Not just a matter of knowledge: the Katrina debacle, Environmental Hazards, 7(2), 141-149.


