31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Decision support system for resource allocation in disaster management

Russell Kondaveti and Aura Ganz, University of Massachusetts, Amherst

***Abstract*—Natural and man-made disasters, such as earthquakes, floods, plane crashes, high-rise building collapses, major nuclear facility malfunctions, pose an ever-present challenge to public emergency services. Disasters may result in a large volume of responders arriving on-scene to provide assistance to victims. Coordination of responding resources is a major problem in disasters. In this paper we introduce a decision support framework built on rapid information collection and resource tracking functionalities. Based on this information collected from emergency response service agencies, operation research techniques are used to find an optimal solution for resource deployment and dispatching.**

I. Introduction

Over the past quarter century, 3.4 million people lost their lives due to disasters worldwide. Natural and man-made disasters, such as earthquakes, floods, plane crashes, high-rise building collapses, or major nuclear facility malfunctions, pose an ever-present challenge to public emergency services. Such disasters test the ability of communities and nations to effectively protect their populations and infrastructure, to reduce both human and property loss, and to rapidly recover. Disaster response and recovery efforts require timely interaction and coordination of public emergency services in order to save lives and property.

Existing so-called disaster management systems [1-3] usually are mere information systems, which are used for graphical representation of disaster-relevant data. However, all these systems do not allow the next and more important step, namely active decision support by providing an optimized schedule for the available resources to the areas requesting help.

To improve the identification and management of response assets in a mass-casualty incident, as well as to help coordinate the initial response, we propose a decision support system for resource allocation in disaster management. Using information collected from emergency response agencies, operation research techniques are used to find an optimal solution for allocation of resources to the disaster site. The system architecture of the decision support system is discussed in the Section 2 and the decision support algorithm is presented in Section 3. In Section 4, we introduce and study a hypothetical disaster scenario and Section 5 concludes the paper.

II. System Architecture

The decision support system architecture is mainly composed of the following components as shown in the Figure 1.

A. *Information Collection Framework*

The information collection framework lays the communication infrastructure in the disaster scenario to obtain the information about the location of the victims and resources, e.g., the DIORAMA system developed by the authors [4].

B. *Available Resources Database*

This is the database of the available emergency response resources within at least 100 mile radius of the disaster area. EMS teams, Fire fighters, police, HAZMAT teams are examples of emergency response resources.

C. *Resource Deployment Guidelines*

These include the priority ratings for each disaster location (cluster) which determines how important the resources are to the locations and also the required resources to mitigate the risk in each cluster of victims. These guidelines are provided by the triage supervisors present at the disaster sites.

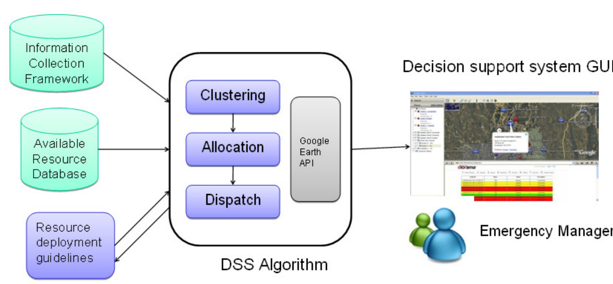

Fig .1. Decision support system architecture

III. Decision support System Algorithm

The decision support system algorithm (DSS Algorithm) can be broadly divided into three phases: clustering the victims, resource allocation and resource dispatching as detailed below.

A. *Phase I – Clustering the victims*

In this phase, the victims are clustered based on their

978-1-4244-3296-7/09/$25.00 ©2009 IEEE

geographical proximity using the Euclidean distance as the measure. The Euclidean distance between any two objects in the cluster is not affected by the addition of new objects to the cluster analysis. The input to this phase includes: the number of victims and their location as collected by the information collection framework [4]. The output is a table mapping the victims to clusters, priority ratings (s_{ij}) and demand matrix (d_{ij}) of the cluster. Priority rating of the cluster (s_{ij}) represent how important are the resources of type i to the cluster j on a scale of 1 to 10. Demand matrix represent the number of resources of each type needed at the disaster sites. Priority ratings and demand matrix are provided by the emergency managers on site.

Mathematically the clustering problem is represented as follows:

$$Minimize: \sum_{i=1}^{n} \sum_{j=1}^{C} w_{ij} \left\| a_i - z_j \right\|^2 \qquad (1)$$

Subject to

$$\sum_{j=1}^{C} w_{ij} = 1, \forall i = 1, \ldots, n$$

Where, n = number of victims; C = number of clusters;
$a_i = i^{th}$ victim location.

Decision Variables:

z_j = centroid of the jth cluster;
w_{ij} = 1 (if i^{th} victim belongs to j^{th} cluster);
= 0 (Otherwise);

Clustering is a NP-hard problem. We chose to solve this problem using an approximate algorithm, agglomerative hierarchical clustering [5].

B. *Phase II – Resource Allocation*

In this phase we determine the number of emergency resources that can be allocated at each cluster which minimizes the overall risk. We define risk as the fraction of unsatisfied demands. The objective is to minimize the overall risk by allocating the constrained resources. The constraints in this problem are the available number of resources. The input to this phase includes: the Demand matrix (d_{ij}) and Priority ratings of the cluster (s_{ij}), provided by the emergency managers on site, number of clusters and available number of resources. The output is the allocation table which represents the number of resources of each type allocated to each of the clusters.

Mathematically the problem can be formulated as,

$$Minimize: \sum_{j=0}^{C} \sum_{i=0}^{m} s_{ij}\left(1 - \frac{x_{ij}}{d_{ij}}\right) \qquad (2)$$

Subject to $\Sigma_j\, x_{ij} \le r_i$ *for all i,j and Integer*
$x_{ij} \le d_{ij}$ *for all i,j and Integer*
$x_{ij} \ge 0$ *for all i,j and Integer*

where, C: Number of clusters; m: Number of resource types; r_i: Available number of resources of type i; s_{ij}: Priority Index of cluster j with respect to resource of type i; d_{ij}: Total number of resources of type i needed by cluster j.

Decision Variables:

x_{ij}: Number of resources of type i allocated to cluster j;

This is an integer programming problem. The output of this phase is the optimal resource allocation table (x_{ij}) which provides the optimal number of emergency response resources that can be deployed at each cluster reducing the overall risk.

C. *Phase II – Resource Dispatching*

In the last phase, we find the nearest resource warehouse that can cater the demands of the cluster and dispatch the resources accordingly to the disaster site. This is also an integer programming problem where the objective function is to minimize the cost over dispatching the resources to the clusters. Mathematically the dispatch problem is given by:

$$Minimize: \sum_{i=0}^{m} \sum_{j=0}^{C} \sum_{k=0}^{w} c_{ijk} * y_{ijk} \qquad (3)$$

Subject to $\Sigma_k\, y_{ijk} = x_{ij}$ *for all i, j, k*
$\Sigma_j\, y_{ijk} \le r_{ik}$ *for all i, j, k*

Where, C: Number of clusters; m: Number of resource types; w: Number of resource warehouses; x_{ij}: Number of resources of type i allocated to cluster j (This is obtained from the Clustering Phase); r_{ik}: Number of resources of type s located at warehouse k; c_{ijk}: cost associated with dispatching resources of type i to cluster j from resource location k.

Decision Variables:

y_{ijk}: Total number of resources of type i dispatched to cluster j from resource location k.

The allocation and dispatch problems are solved by using the open source linear programming problem solver LPSolve. The output of this phase is the optimal dispatch table (y_{ijk}) which represents the number of emergency resources needed to be dispatched from the warehouses to disaster sites. This information is then transformed into a KML file which graphically represents the resource deployment on Google earth as shown in the Figure 2 using Google Maps API. The decision support system is a Microsoft Windows application developed using C# .Net Framework, LPSolve API and Google Maps API.

IV. Hypothetical Disaster Scenario

In this section, we will describe a hypothetical disaster scenario and explain how the decision support system deploys emergency resources. Assume that serial bomb blasts have occurred in and around the town of Amherst; there were 3 bomb blasts, one each in Amherst, Sunderland and Hadley. In the area of Sunderland, 7 persons have been killed (Black), 5 persons have been severely injured (Red), 10 persons have been lightly injured (Green) and 5 of the victims are moderately injured (Yellow). Similarly there are victims in the areas of Hadley and Amherst as mentioned in Table I, which represents the victims in each of these clusters.

TABLE I
SEVERITY OF INJURY AND NUMBER OF VICTIMS

Location	Severity of Injury			
	Red	Yellow	Black	Green
Amherst	10	2	2	1
Hadley	2	3	10	0
Sunderland	5	3	7	0

The emergency managers present in each cluster are required to assign the priority ratings to the cluster with respect to the emergency response resource on a scale of 1 to 10 through the Information collection framework. This table is termed as Priority ratings matrix (Table II).

TABLE II
PRIORITY RATINGS MATRIX

	EMS	Fire fighters	Police
Amherst	10	10	5
Hadley	5	5	5
Sunderland	8	8	5

The emergency responders on site report the demands necessary through the information collection framework. This is stored as another table in the database. These two matrices, priority ratings matrix and demands matrix, constitute the resource deployment guidelines. Table III represents the demand matrix for this scenario.

TABLE III
DEMAND MATRIX

	EMS	Fire fighters	Police
Amherst	20	20	15
Hadley	5	10	5
Sunderland	10	15	10

Table 4 represents the available number of resources at each emergency resource warehouses in Amherst, Hadley and Sunderland respectively.

TABLE IV
RESOURCE MATRIX

	EMS	Fire fighters	Police
Amherst	5	10	10
Hadley	10	10	10
Sunderland	15	20	10

In the second phase of the algorithm, we determine the allocation table that represents the emergency response resources that are allocated to the clusters to minimize the overall risk. The allocation table (Table V) is calculated by solving the integer programming problem (2) as mentioned in Section 3. In the final phase, using the allocation table (Table V) and the cost to dispatch table (Table VI) as constraints, the final dispatch table (Table VII) is calculated.

TABLE V
ALLOCATION MATRIX

	EMS	Fire fighters	Police
Amherst	20	20	15
Hadley	0	5	5
Sunderland	10	15s	10

The cost matrix represents the response time in minutes calculated based on the distance between the cluster and resource warehouse acquired from Google maps API. Response time is defined the elapsed time from the time a call is dispatched in the communications center until the first unit arrives on the scene.

TABLE VI
COST MATRIX

	EMS			Fire fighters			Police		
	k1	k2	k3	k1	k2	k3	k1	k2	k3
Amherst	2	7	13	2	7	13	2	7	13
Hadley	7	3	11	7	3	11	7	3	11
Sunderland	11	13	7	11	13	7	11	13	7

k1, k2 and k3 represent the resource warehouses located at Amherst, Sunderland and Hadley respectively.

The Table VII represents the dispatch matrix for the above hypothetical disaster scenario. This table shows the number of resources that need to be dispatched from each of the resource warehouses to the disaster sites.

TABLE VII
DISPATCH MATRIX

	EMS			Fire fighters			Police		
	k1	k2	k3	k1	k2	k3	k1	k2	k3
Amherst	5	10	5	10	10	0	10	5	0
Hadley	0	0	0	0	0	5	0	5	0
Sunderland	0	0	10	0	0	15	0	0	10

The decision support system generates the KML file which graphically represents the location of the victims and resources on Google earth as show in the Fig. 2.

For the hypothetical disaster scenario described above, we have considered two cases one with infinite resources available at each resource and the other case with finite resources as shown in Table IV. As mentioned earlier in the paper, risk is defined as the fraction of unsatisfied demands. The risk at cluster j ($R_j(t)$) is calculated using equation (4) and the cluster risk computation is given in equation (5).

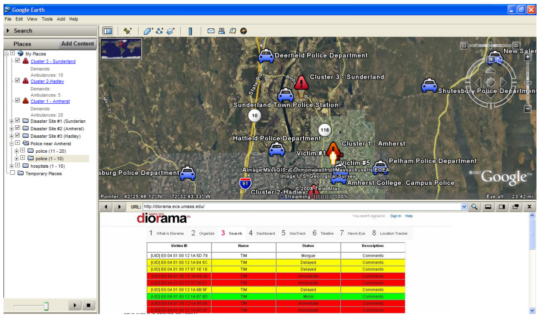

Fig. 2. Decision support system interface on Google earth

$$R_j(t) = \frac{\sum_{i=0}^{m} s_{ij} * \left(1 - \frac{\sum_{k=0}^{w} y_{ijk} * u_{ijk}(t)}{d_{ij}}\right)}{\sum_{i=0}^{m} s_{ij}} \quad (4)$$

$$R(t) = \frac{\sum_{j=0}^{c} R_j(t)}{C} \quad (5)$$

where $u_{ijk}(t)$ is a Step function, $u_{ijk}(t) = 1$, for $t \geq c_{ijk}$; for all i,j,k and = 0, otherwise; s_{ij}: Priority Index of the cluster j with respect to resource of type i; d_{ij}: Total number of resources of type i needed by cluster j; c_{ijk}: cost associated with dispatching resources of type i to cluster j from resource location k; y_{ijk}: Total number of resources of type i dispatched to cluster j from resource location k.

Fig. 3 depicts the risk per cluster versus time. The plot suggests that rescue efforts are prioritized to mitigate the higher risk at cluster 1 and cluster 3 as there are more critical victims in those clusters (see Table I).

Fig. 4 depicts the overall risk versus time for both the finite and infinite resources cases. The time it takes to completely mitigate the risk for the infinite resource case is 7 minutes. In the finite resources case only 80% of the risk is mitigated in 7 minutes. Such a plot can illustrate for the resource manager what are the risks involved with given resource demands and available resources. In this case, more emergency response resources can be placed near Cluster 2 in order to perform emergency response activities more efficiently.

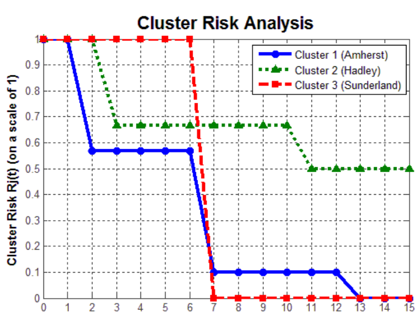

Fig. 3. Cluster Risk ($R_j(t)$)Analysis

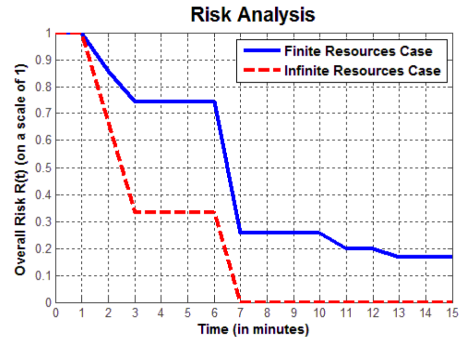

Fig. 4. Overall Risk ($R(t)$) Analysis

V. Conclusion

We have introduced and demonstrated a decision support system for emergency managers. The proposed tool can help emergency response organizations not only to perform emergency response activities efficiently but also to perform emergency resources planning (amount and location of resources).

The decision support system integrated with real-time emergency response information collection system developed by the authors [4] can be a comprehensive solution for resource management in disaster response.

Acknowledgment

This project was supported in part by the following grants: Grant number ANI-0434985 from the National Science Foundation and Grant Number R21LM008942-01A2 from the National Library of Medicine. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Science Foundation, National Library of Medicine or the National Institutes of Health.

References

[1] Fiedrich, F., F. Gehbauer, and U. Rickers, "Optimized Resource Allocation for Emergency Response after Earthquake Disasters," Safety Science, Vol. 35, 41-57, 2000.

[2] Fiedrich, F., "An HLA-Based Multiagent System for Optimized Resource allocation after Strong Earthquakes," Proceedings of the 2006 Winter Simulation Conference, 2000.

[3] Sherali, H.D., Desai, J. and Glickman,"Allocating emergency response resources to minimize risk under equity considerations," American Journal of Mathematical and Management Sciences, Vol. 24(3/4), pp.367-410. 2004.

[4] http://diorama.ecs.umass.edu

[5] Xu, R., D. Wunsch, "Survey of Clustering Algorithms" in IEEE Transactions on neural networks, Vol. 16, No. 3, May 2005.