A study on the effective disaster resources assessment and allocation for emergency response

Sumin Han, Gyusun Hwang, Sangyun Choe, Jinwoo Park

***Abstract*— A disaster is the serious disruption of the functioning of a community. Disasters such as flood, fire, and earthquake affect thousands of people annually. Moreover, disasters occurred near the riverside structure cause human, material, economic, and environmental losses. To deal with the disasters, the disaster response system takes charges of preparation, response, and recovery. This study seeks to explore the necessity of disaster resource assessment and allocation for emergency response. We evaluated the assessment of disaster response resources and allocated them to the damaged areas. The simulation study was conducted in order to verify the utilization of developed algorithm. This research will be helpful to decision maker who want to allocate the disaster recovery resources effectively.**

***Index Terms*— Riverside Structure, Emergency Response, Resource Assessment, Resource Allocation**

I. Introduction

In the 2000's, the number of natural disasters is increasing all over the world and the damages of the natural disasters is gradually getting serious. According to data from the CRED International Disasters Database (EM-DAT), the number of natural disasters appears to have increased worldwide. In the decade 1990-1999, natural disasters occurred 2676 times, but in the period 2000-2009, the number of occurrences rose to 4015. Furthermore, the annual estimated economic losses from natural disasters are almost US$ 143 billion on average from 2001 to 2010. The impact of disaster cuts across the economy, the environment, and institutional development.

In Korea, damages to a disaster are not negligible levels. Property damage caused by typhoon is about 140 trillion won from 1904 to 2009. In addition, 3 trillion won budget is being sent for emergency repair for the damaged areas. Like this, despite the fact that damage occurs repeatedly each year, R & D budget investment ratio at the national level for the disaster are staying in the 1% level. Therefore, a state of disaster response system is incomplete and the new system is indeed necessary.

The purpose of the system for disaster is to reduce the damage caused by the disaster. It will be the most critical for the proper planning and execution of disaster response and recovery. According to Moe and Pathranarakul (2006), there are four critical activities in the life-cycle of natural disaster management. The life-cycle starts with the mitigation phase, preparedness, and response and ends in recovery activity as shown in the following Table 1. Especially, in the response and recovery stage, it is required to address the importance of need assessment, coordination, information exchange, and logistics management.

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Table 1: Four critical activities in the life-cycle of natural disaster management

Phase	Activities
Mitigation	Structural and non-structural measures undertaken to limit the adverse impact of natural hazards, environmental degradation and technological hazards
Preparedness	Activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and properly from threatened locations.
Response	The provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected. It can be of an immediate, short-term, or protracted duration.
Recovery	Decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk.

Thus, it is essential to ensure the resources required for disaster recovery and to efficiently allocate the resources to the damaged areas to reduce further damage to spread.

Damages caused by natural disasters are usually the cases that occurs simultaneously in several areas. At this time, the number of resources that can be used for recovery and repair in the field is limited. Therefore, for allocating each resource to the recovery site to meet the needs of the resource, recovery is required to be able to be smoothly carried out.

II. The Purpose of Study

In this paper, we focused on this appropriate response, when emergency recovery is needed. In order to prevent additional damage from spreading, appropriate emergency recovery has to be conducted. We introduce an effective methodology and algorithm for resource allocation in disaster recovery.

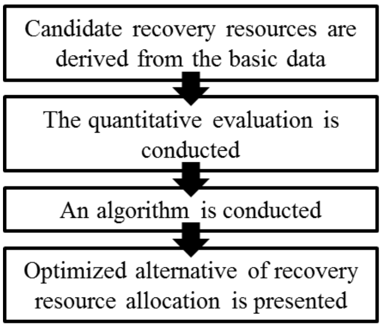

Figure 1: The process of methodology for resource allocation in disaster recovery

The process of methodology is in the following Figure 1. First, candidate recovery resources that can be used at the site of recovery are derived from the basic data and then, the quantitative evaluation is made for each candidate recovery resource considering factors which the resources have such as distances, construction ability, etc. With results of the evaluation, an algorithm is conducted to appropriately assign the resources at each repair site. As a result, optimized alternative of recovery resource allocation is presented for the recovery required for each damaged areas.

This study may be useful in the management and utilization of resources in the recovery plan. In this paper, we proposed a methodology and algorithm to allocate recovery resources appropriately according to the status of the recovery site, and showed the results through experiment. The result presented in this paper seems to help to create the resource management and resource use plan.

III. Literature Review

There are many studies on resource allocation for natural disaster. But, studies on the resource allocation method with an evaluation of the recovery of resources are not enough. Most of the researches are on routing planning of vehicles and overall disaster management system.

F. Fiedrich et al. (2000) introduce dynamic optimization model. The model uses detailed descriptions of the operational areas and of the available resources to calculate the resource performance and efficiency for different tasks related to the response with simulated Annealing (SA) and Tabu Search (TS) method.

Russell Kondaveti and Aura Ganz (2009) introduce a decision support framework and system built on rapid information collection and resource tracking functionalities. The decision support system integrated with real-time emergency response information collection system developed. 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. Nevertheless, it does not consider the state of the resource, and does not take into account a number of environmental factors.

Lee, Seul-Bi et al. (2013) is to consider the factors for priority among facilities and present framework of restoration resource allocation model. The framework only but has been configured, the optimal assignment proposal is not provided.

In addition to these, there are more researches on resource allocation for natural disasters but researches through the evaluation of the resources were not enough.

In this paper, we not only took into account the state of the resource and environmental factors but also evaluated the resources with quantitative method. As the final outcome, we presented optimized alternative of recovery resource allocation for the recovery required for each damaged areas.

IV. Resource Assessment

A. *Characteristics of assessment*

Assessment is essential to determine of qualitative or quantitative value of the project success related to concrete situation. There are many requirements to project assessment regarding some point of views. Based on purpose of assessment, we classify the assessment into 2 groups: operational and effective, because different evaluation approach is need depending on the purpose of assessment. We also illustrate the characteristic of assessment based on 4 criteria.

The reason this study try to assess the disaster recovery resources are to allot the resources more effectively. From the below Table 2, our study is for operational purpose and middle phase assessment. Our goal is to manage the disaster recovery project and improve the efficiency considering the status of the current circumstance. In this reason, we should evaluate the resources by operational scope and in the middle of the decision status. Also, demanding on the rapid responsiveness, our assessment subject is internal due to time limitation.

After drawing the demand of the resources, available resources are listed into the database. This study evaluates the resources ability by using our developed formulation. And outcome of the assessment will be used in resource allotment as the baseline data.

B. *Elements of the assessment*

For conducting the assessment, we generate the elements based on the disaster recovery resources' characteristics. And the extracted elements are as follows: Resource, Moving distance, Usage period, Construction Capability, Holding volume. Outcome of assessments are used in the allotment of the resources. For this reason, we have to quantify the elements.

- **Moving distance:** Distance from current position to devastated area
- **Usage period:** Current date – Manufactured date
- **Construction capability:**
  $$\frac{(\text{Ordinary capability} - \text{Minimum capability})}{(\text{Maximum capability} - \text{Minimum capability})}$$
- **Holding volume:** Company holding volume/ Demand volume

Table 2: Characteristics of assessment based on criteria

Criteria	Classification	Characteristic
Purpose	Operational	- It evaluates the project management and its stakeholder's ability. - It focuses on the project suitability and efficiency.
	Effective	- It diagnosis the gap between project goal and project outcome.
Phase	Prior	- It analyses the project plan's validity.
	Middle	- It evaluates on-going project system improvement based on the operational assessment.
	Posterior	- It assesses the project outcome and effectiveness.
Subject	Internal	- It serves the recheck step for project goals and plans so as to take some project quality improvements. - After project completion, it is hard to take an objectivity and reliability, due to absence of external view point.
	External	- It is able to take dependency, objectivity, and specialty of project assessment.
Contents	Economical	- It is able to find a project economical effectiveness.
	Administrative	- It assesses the project political effectiveness, and it has tendency to be non-qualitative assessment.
	Technical	- It evaluates the project technical problem and it is used in prior assessment.

C. Weighted value setting

Elements of the assessment are assigned to weighted value so as to consider their priority. Weighted values are calculated based on the questionnaires to field experts. There are many methods to set weighted values: Rank sum, Rank inverse sum, Rank multiplication, etc. This study applies the Rank sum method basically.

Rank sum method is based on the relative importance idea. The higher rank factor is given to higher weighted value, and the lower rank factor is assigned to lower weighted value. The formulation of the rank sum method is as follows.

n : Number of factors

r_i : Rank of factor i among factors

W_i : Final weighted score of factor i

$$W_i = \frac{n - r_i + 1}{\sum_{i=1}^{n}(n - r_i + 1)}$$

Table 3: Example of the weighted value using Rank sum

	Moving distance	Usage period	Capability	Holding volume
Priority	2	4	3	1
Weighted value	0.13	0.27	0.20	0.07

D. Conducting resource assessment

For evaluating the resources, we generate formulas with weighted value and desired values. First, each elements are multiple by weighted value. Then, Assessments are deduced by summing up the result. The formulas are as follows:

$$\sum_{i=1}^{n} \alpha * MD_j + \beta * UP_j + \gamma * CaP_j + \delta * HV_j$$

Since the disaster may affect damage to a number of sites, we will evaluate the resources according to each of the affected area. The outcome of assessment is used in allotment algorithms. And following table shows the example of the assessment results.

Table 4: Example of the assessment result

	Moving Distance			Usage Period	Capability	Holding Volume	Assessment		
	A	B	C	Common	Common	Common	A	B	C
Fork crane 1	25	14	40	4	50	0.3	14.42	12.95	16.42
Fork crane 2	30	12	5	2	20	0.3	8.55	6.15	5.22
Fork crane 3	19	4	32	8	80	0.1	20.67	18.67	22.41
Fork crane 4	19	4	32	8	80	0.7	20.71	18.71	22.45

V. Resource Allocation

A. *Characteristics of allocation problem*

After resource assessment, disaster response resources has to be deployed to damaged structure. Since there are a lot of factors which are related to disaster scene, it is very complex problem.

In the allocation problem, this study tries to build the good resource allocation plan. The allocation plan contains the destination, amount, and allocation timing of every disaster response resources. The allocation problem uses the result of resource assessment and disaster scene assessment. The disaster scene assessment contains the resource demand and priority of each disaster scenes. And that is conducted by construction and administration specialist. There is the detailed input and outputs in Table 5.

Table 5: Input and Output of Resource Allocation

Category	
Input	resource assessment disaster scene assessment amount of available resource resource demand of disaster scene
Output	Destination of resource Amount of usage Allocation timing.

B. *Formulation*

Before the solution, detailed formulation is needed for its precise problem definition. In this study, this problem is formulated by mixed integer problem.

1) Notation

- Set of resource category: G / g = 1 ~ |G|
- Set of resource: R / r = 1 ~ |R|
- Set of damaged area: S / s = 1 ~ |S|
- Time horizon: I / i = 1 ~ |S|

2) Data

- Category information of each resource:

$$C = [C_{rg}]\ (|R| \times |G|) \begin{cases} 0, & \text{not included} \\ 1, & \text{included} \end{cases}$$

- Demand information:

$$D = [d_{gs}]\ (|G| \times |S|)$$

- Current amount of resource:

$$W = [w_r]\ (|R| \times 1)$$

- Result of resource assessment:

$$E^1 = [e^1_{rs}]\ (|R| \times |S|)$$

- Result of disaster scene assessment:

$$E^2 = [e^2_{si}]\ (|S| \times |S|)$$

3) Objective function

- Maximize the summation of assessment.

$$\max_{x,y} f(X,Y) = \sum_i \sum_r \sum_s \frac{e^1_{rs} x^i_{rs}}{w_r} + \sum_s \sum_i e^2_{si} y_{si}$$

4) Decision Variable

- Using amount of resource *r* in disaster scene *s* at *i*th plan:

$$X^i = [x^i_{rs}]\ (|R| \times |S|)$$

- Whether disaster scene *s* is allocated in *i*th plan:

$$Y^i = [y_{si}]\ (|S| \times |S|),\ \ y_{si} = \begin{cases} 0, & \text{not allocated} \\ 1, & \text{allocated} \end{cases}$$

5) Constraints

- Current amount constraint:

$$X^i \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \le W\ (\forall i)$$

- Number of allocation constraint:

$$Y \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix}$$

- Resource usage constraint:

$$\sum_r c_{rg}\, x^i_{rs} = y_{si} \times d_{gs}\ \ (\forall\, i, g, s)$$

C. *Heuristic Approach*

If the size of the problem increases, it may take long time to compute optimal solution with mathematical programming. So heuristic approach is suggested in this study. The heuristic rule follows these steps.

1. Initiate
   A. Set time ← 1
2. Select the disaster scene
3. Select resources for result in step 2.
   A. If we have enough resources, allocate them.
   B. If not, check the disaster scene is not available.
4. Do all disaster scenes are allocated?
   A. If yes, finish.
5. Is there available and not allocated disaster scene?
   A. If yes, go back to step 2.
   B. If no, increase time and go back to step 2.

Suggested heuristic algorithms consist of disaster scene selection and resource selection. In disaster scene selection, there are four heuristic rules are applied.

1. Select the disaster scene with maximum assessment score.
2. Pairing all disaster scene and resource with sum of its assessment score. Select the disaster scene with maximum number of the pair.

3. Pairing all disaster scene and resource with sum of its assessment score. Select the disaster scene with maximum summation of the assessment score.
4. Select the disaster scene with maximum gap between most assessment and 2nd most assessment score.

In resource selection, there are two rules are applied.

1. Select the resource with maximum assessment score.
2. Select the resource with maximum gap between most assessment and 2nd most assessment score.

D. *Simulation Experiment*

Eight heuristic rules, which are combination of rules in two stage were applied to simulation experiment to compare their results.

1) *Simulation Setting*

Table 6 is the setting of simulation experiment.

Table 6: Simulation Setting

Item	*Contents*
Number of experiment	100
# of resource category	4
# of damaged disaster scene	4,8,12,16
Resource demand	Unif[0,10]
Resource assessment score	Unif[0,100]
Disaster scene assessment score	Unif[0,100]
# of resources per category	Unif[1,5]
Stocks of each resources	Unif[5,10]

2) *Result*

Table 7, 8, 9, 10 is the result of simulation experiment according to the number of disaster scene. Figure 2, 3, 4 is the result of simulation result which summarize the results of all disaster scene settings.

The combination of rule 4 and rule 1 has best performance. Since the gaps between disaster scene selection rules are not significant, other rules may do better than rule 4 in certain situations. But the gap between resource selection rules is significant.

Table 7: Result with 4 disaster scenes

Resource \ Disaster scene	*1*	*2*	*3*	*4*	*total*
1	*1107.92*	*1106.18*	*1108.76*	*1121.92*	*1111.20*
2	*828.09*	*828.31*	*826.78*	*830.88*	*828.51*
total	*968.02*	*967.24*	*967.77*	*976.40*	*969.86*

Table 8: Result with 8 disaster scenes

Resource \ Disaster scene	*1*	*2*	*3*	*4*	*total*
1	*2107.60*	*2084.34*	*2102.64*	*2150.27*	*2111.22*
2	*1861.87*	*1849.58*	*1859.51*	*1894.66*	*1866.40*
total	*1984.74*	*1966.96*	*1981.07*	*2022.46*	*1988.81*

Table 9: Result with 12 disaster scenes

Resource \ Disaster scene	*1*	*2*	*3*	*4*	*total*
1	*3075.97*	*3030.46*	*3071.57*	*3131.33*	*3077.33*
2	*2867.42*	*2826.59*	*2861.91*	*2909.89*	*2866.45*
total	*2971.70*	*2928.52*	*2966.74*	*3020.61*	*2971.89*

Table 10: Result with 16 disaster scenes

Resource \ Disaster scene	*1*	*2*	*3*	*4*	*total*
1	*4004.21*	*3936.05*	*3985.92*	*4068.85*	*3998.76*
2	*3848.93*	*3774.40*	*3828.94*	*3915.14*	*3841.85*
total	*3926.57*	*3855.23*	*3907.43*	*3992.00*	*3920.30*

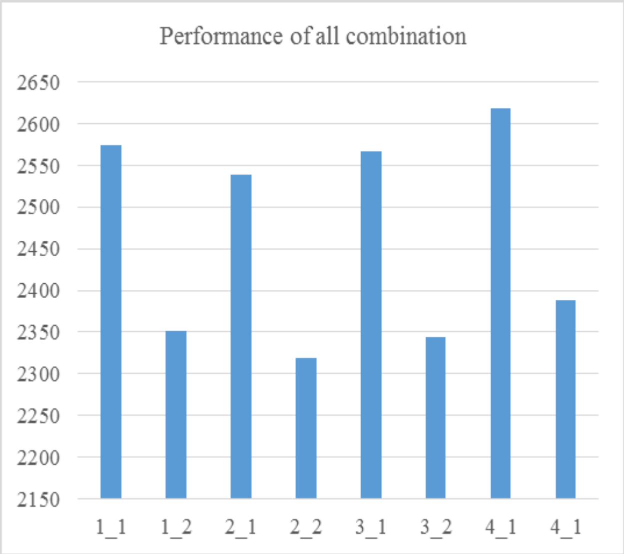

Figure 2: Performance of all combination of rules

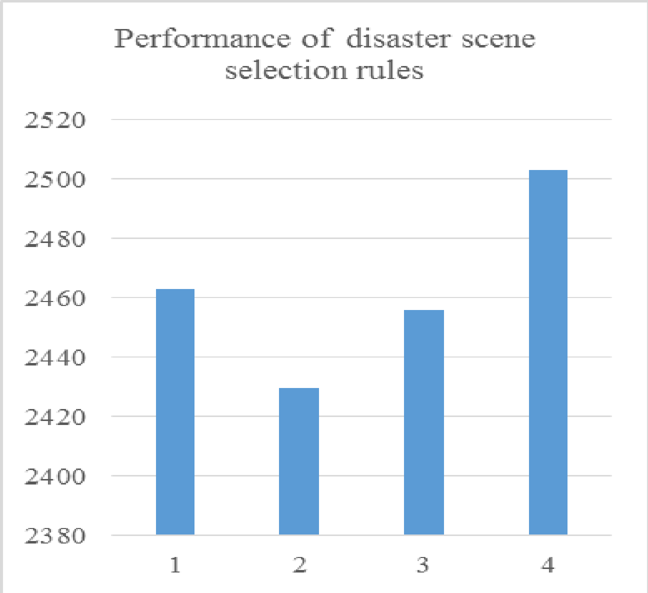

Figure 3: Performance of disaster scene selection rules

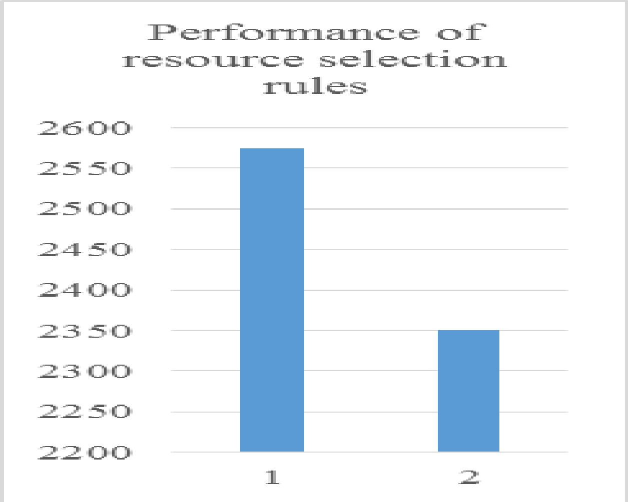

Figure 4: Performance of resource selection rules

VI. Conclusion

This study suggested the disaster resource assessment and allocation algorithm. The suggested assessment algorithm considered various attributes related to resource itself and its environment to build the assessment score.

With the result of assessment, the allocation algorithm builds the resource allocation plan which contains the destination, using amount, and timing. To build resource allocation plan, this study suggested heuristic algorithm. And simulation experiment was conducted to verify the their performance

Since the algorithms of this study can build the allocation plan with relatively small computation resources, the disaster response system can apply them in disaster response.

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