Resource Optimization Model for Managing Conflict in Tsunami Relief Operations in Thailand

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***ABSTRACT*:** The Tsunami that took place in Sumatra Island on December 26, 2004 has brought tremendous loss to coastal areas of most of South East Asian countries, including Thailand. Despite substantial contributions from various governmental and non-governmental organizations, conflicts still remain, especially with regard to the resource allocation and policy decision making. The main problems found are: resource mismatching, aid duplication, unfair distribution, and inefficient resource uses. In this paper, we propose a new resource optimization model to manage the complexity of resource conflict and to define efficiently fair resource allocation schemes. While two well-known resource allocation theories – utilitarian and egalitarian - are employed, this model also considers that an increase in the benefits of victims can vary based not only on an amount of resources provided, but also the characteristics of resources. Finally, we have integrated the models in our prototype system developed for spatial resource allocation purpose; then it has been examined by using the historical data gathered from tsunami affected area in Thailand. Compared to the current resource allocation schemes made by aid agencies, the result has shown that schemes generated by this system could increase the social welfare of the area affected by tsunami. Some assumptions and limitations of models are also discussed in this paper.

KEYWORDS: Conflict, Resource Optimization, Tsunami

1 INTRODUCTION

Fair and systematic resource allocation is one of the most crucial issues in many fields, especially those which have to be dealt with limited resources, such as natural resources and environments, construction, health, and business. In the field of natural disaster, particularly during post-disaster operations, this issue plays an important role in designing the way to optimize multiple types of resources provided by many aid agencies.

By investigating the tsunami case in Thailand that took place in December, 2004, important problems found regarding resource allocation are: mismatching between needs and aids, duplication of aids, unfair distribution, and inefficient allocation of resources. Many agencies have realized these problems; therefore immediately after tsunami took place, cooperation agencies were formed. Moreover, many works by researcher have been proposed to solve the conflict in tsunami relief operations in Thailand.

Honda and Ninsawat (2005) have developed the geographic information systems called Tsunami Web Map Sever aiming at contribute to the relief of Tsunami disaster by saving time for data collection, reducing duplication of efforts. Weesakul (2005) has developed a graphic simulation tsunami event conducted by using the numerical modeling of tsunami propagation for mitigation measure and planning. Disaster Tracking Recovery Assistance Center (DTRAC, 2006) has tracked the work of aid agencies and made it public through website when each knows what others are doing, by which duplication of aid may decrease and gaps in aid are identified faster. South Andaman Network (SAN, 2006) has coordinated between the local government organization and the local people to facilitate sharing the information between these parties and compromising when conflicts occurred.

Though much research for facilitating tsunami relief operation has been done continuously, most of them have focused on reporting the damages and information sharing, not many of such attempts focused on how decision makers can utilize that information. More specifically, though decision makers can know the updated data related to tsunami victims, they still need to deal with fairness issue such as the types of resources and their amount which should be distributed to each tsunami affected areas.

This paper proposes resource optimization models which could be integrated in the decision support system for generating fair resource allocation schemes. We develop the models by employing two well known resource allocation theories – utilitarian[1] and egalitarian[2]; and consider the characteristics of resources as the criteria for the increase in the utility of each individual. According to this, we have classified resources into two types: dependent resources and independent resources.

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[1] Utilitarianism aims to maximize the summation of all utilities of the members of a society Detailed about this concept can be found in (Harsanyi, 1955; Sen, 1979; Fishburn, 1984; Broome, 1987).

[2] Egalitarianism aims to maximize the utility of the weakest in the society. Detailed about this concept can be found in (Rawls, 1971, Rawls, 1998; Wolf, 1998)

2 INDIVIDUAL UTLITY FUNCTIONS AND THEIR ASSUMPTIONS

In general economic theories, benefits of resources supplied to the individual are usually converted into monetary term. However, in the field of natural disaster resource management, it is difficult to evaluate the benefit of resources allocated to victims in terms of money since there are no markets in the process. In other words, the victims of natural disaster have received resources from government or aid agencies without considering the actual price of the resources themselves.

To model the utility function of each individual, some assumptions are made as follows:

(a) A village affected by tsunami is assumed to be a unit of individual for developing a utility function.

(b) Utility function of each individual is concave and follows the quadratic linear utility function.

(c) Marginal utility of each village is gradually diminished when provided with each unit of resource; and it becomes zero when the total resources held by that particular village are more than or equal to its total amount of needs.

(d) Each type of resource is considered its utility separately. In other words, no correlation of utility is allocated multiple resources at the same time.

2.1 Marginal Utility Function of Villages Affected by Tsunami

Based on the assumptions that have been made in the previous section, a marginal utility function of each village can be formulated (Fig. 1). The marginal utility then can be measure by calculating the area under graph which is shown into two cases.

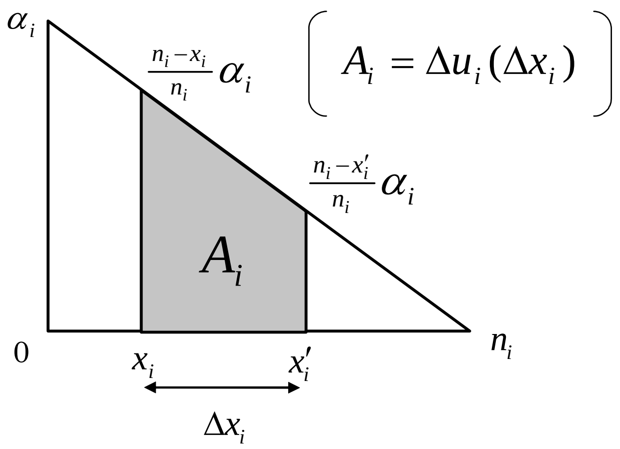

Figure 1: individual marginal utility function

Case1: The summation of current resource of the individual *i* before allocation and resources allocated at that time is less than or equal to the total need ($x_i + \Delta x_i \le n_i$)

$$u_i(\Delta x_i) = \frac{1}{2}(\Delta x_i)\left[\alpha_i\left(\frac{n_i - x_i}{n_i}\right) + \alpha_i\left(\frac{n_i - x_i'}{n_i}\right)\right]$$

$$= \frac{1}{2}(\Delta x_i)\left[\alpha_i\left(\frac{n_i - x_i}{n_i}\right) + \alpha_i\left(\frac{n_i - (x_i + \Delta x_i)}{n_i}\right)\right]$$

$$= \frac{1}{2}(\Delta x_i)\left[\alpha_i\left(\frac{2n_i - 2x_i - \Delta x_i}{n_i}\right)\right]$$

$$= \frac{\alpha_i \Delta x_i}{2}\left(\frac{2n_i - 2x_i - \Delta x_i}{n_i}\right)$$

$$= \alpha_i \Delta x_i\left(1 - \frac{x_i}{n_i} - \frac{\Delta x_i}{2n_i}\right) \qquad (1)$$

Case2: The summation of current resource of the individual *i* before allocation and resources allocated at that time is more than total need ($x_i + \Delta x_i > n_i$). This case will create the minus of marginal utility. Therefore according to the assumption that marginal utility will not be less than zero, we assign $x_i' = n_i$ for this case.

$$u_i(\Delta x_i) = \frac{1}{2}(\Delta x_i)\left[\alpha_i\left(\frac{n_i - x_i}{n_i}\right) + \alpha_i\left(\frac{n_i - x_i'}{n_i}\right)\right]$$

$$= \frac{1}{2}(\Delta x_i)\left[\alpha_i\left(\frac{n_i - x_i}{n_i}\right) + 0\right]$$

$$= \frac{\alpha_i \Delta x_i}{2}\left(1 - \frac{x_i}{n_i}\right) \qquad (2)$$

whereas,

$\Delta u(\Delta x_i)$ = marginal utility of individual *i* when receiving the amount of resource Δx_i

x_i = amount of resource held by individual *i* before the allocation

x_i' = amount of resource held individual *i* after the allocation

Δx_i = amount of resource allocated to individual *i*

n_i = total need of resource by the individual *i*

α_i = comparison parameter of individual *i*

The increases in the marginal utility of each individual (eq. (1) and eq. (2)) are employed in developing the resource optimization model described in the next section.

2.2 Interpersonal Comparison of Utility

Interpersonal comparison of utility is the parameter used to compare the difference among individuals in utility increase when provided with one unit of resource (Harsanyi, 1955; Sen, 1975). This parameter is important when we consider the resource optimization based on utilitarian theory.

We derive how to identify the interpersonal comparison of utility (a_i). To begin with, the resource optimization model has been defined by assuming the weighted linear utility function as the individual utility function; and the summation of the individuals is maximized as the objective function (eq. (3)).

$$Max \quad \sum_i w_i u_i(\Delta x_i, \Delta y_i, \Delta z_i) \qquad (3)$$

$$s.t. \quad \sum \Delta x_i = X; \quad \sum \Delta y_i = Y; \quad \sum \Delta z_i = Z$$

From the assumptions, each resource can be considered separately. Select *X* as the resource to be optimized. Lagrange equation (eq (4)) is employed.

$$L = W(u_i(\Delta x_i)) + \lambda(X - \sum \Delta x_i) \qquad (4)$$

$$\frac{\partial L}{\partial \Delta x_i} = \frac{\partial W}{\partial \Delta x_i} - \lambda = 0 \qquad for\ \forall_i$$

$$\Leftrightarrow \quad w_i \cdot \frac{\partial u_i(\Delta x_i)}{\partial \Delta x_i} - \lambda = 0$$

$$w_i \cdot \frac{\partial u_i(\Delta x_i)}{\partial \Delta x_i} = w_i \cdot \frac{\partial u_j(\Delta x_j)}{\partial \Delta x_j} \quad (i \neq j)$$

Let,

x_i be amount of resources held by individual *i* before the allocation
x_j be amount of resources held by individual *j* before the allocation
Δx_i be amount of resources allocated to individual *i*
Δx_j be amount of resources allocated to individual *j*
n_i be total need of resources of individual *i*
n_j be total need of resources of individual *j*
w_i be weight of utility function of individual *i*
w_j be weight of utility function of individual *j*
α_i be comparison parameter of individual *i*
α_j be comparison parameter of individual *j*
a_i be interpersonal comparison of utility for individual *i*.
a_j be interpersonal comparison of utility for individual *j*.

<u>Condition 1</u>: $x_i + \Delta x_i \leq n_i$; from eq.(1)

$$u_i(\Delta x_i) = \alpha_i \Delta x_i \left(1 - \frac{x_i}{n_i} - \frac{\Delta x_i}{2n_i}\right)$$

$$w_i \frac{\partial\left(\alpha_i \Delta x_i \left(1 - \frac{x_i}{n_i} - \frac{\Delta x_i}{2n_i}\right)\right)}{\partial \Delta x_i} = w_j \frac{\partial\left(\alpha_j \Delta x_j \left(1 - \frac{x_j}{n_j} - \frac{\Delta x_j}{2n_j}\right)\right)}{\partial \Delta x_j}$$

Let $w_i \alpha_i = a_i; \quad w_j \alpha_j = a_j$

Therefore,

$$a_j = a_i \left\{ \frac{\left(1 - \frac{x_i}{n_i} - \frac{\Delta x_i}{n_i}\right)}{\left(1 - \frac{x_j}{n_j} - \frac{\Delta x_j}{n_j}\right)} \right\} \qquad (5)$$

<u>Condition 2</u>: $x_i + \Delta x_i > n_i$; from eq.(2)

$$\Delta u_i(\Delta x_i) = \frac{\alpha_i \Delta x_i}{2}\left(1 - \frac{x_i}{n_i}\right)$$

$$w_i \frac{\partial\left(\frac{\alpha_i \Delta x_i}{2}\left(1 - \frac{x_i}{n_i}\right)\right)}{\partial \Delta x_i} = w_j \frac{\partial\left(\frac{\alpha_j \Delta x_j}{2}\left(1 - \frac{x_j}{n_j}\right)\right)}{\partial \Delta x_j}$$

Let $w_i \alpha_i = a_i; \quad w_j \alpha_j = a_j$

Therefore,

$$a_j = a_i \left\{ \frac{\left(1 - \frac{x_i}{n_i}\right)}{\left(1 - \frac{x_j}{n_j}\right)} \right\} \qquad (6)$$

whereas,

Substituting the values of $x_i, x_j, \Delta x_i, \Delta x_j, n_i$, and n_j into the eq. (3) or eq. (4) according to each condition (i.e. either $x_i + \Delta x_i \leq n_i$ or $x_i + \Delta x_i > n_i$), a_j can be identified by comparing to a_i

3 PRINCIPLES AND CHARACTERISTICS OF RESOURCES

The usability of each type of resource depends on its characteristics. Some resources may be utilized and then provide benefit for receivers immediately; we term this type an *independent resource*. On the other hand, some resources need to be gathered in a group, or otherwise they could not be utilized[3]; we termed this a *dependent resource*. In this study, these two groups of resources have been classified and incorporated in resource optimization models. The next section describes the detail and some examples of each group.

3.1 Independent Resource

An Independent resource has the value by itself without matching with other resources. Thus the more resources are allocated, the more benefit the individuals will gain. However, since it is assumed that marginal utility of the individuals could not be minus, the resource allocated to each individual is not allowed to go beyond the total need at the time of resource allocation analysis. In the field of natural-disaster resource management, examples of these types of resource are food, water, money, permanent houses[4], *etc.*

3.2 Dependent Resource

Unlike independent resources, dependent resources can provide the benefits to individual only when they are grouped together with others. The generic model showing the benefit of each individual when receiving this type of resource is shown in eq. (7). It is noted that the benefit could become zero if some resources are missing.

$$R_k^d \subseteq N_k^d$$
$$S_k^d \subseteq N_k^d$$
$$v(S) = 0; \quad S_k^d \neq N_k^d$$
$$v(N) = u\left(\min\left\{\left|R_1^d\right|, \left|R_2^d\right|, \ldots, \left|R_k^d\right|\right\}\right) \qquad (7)$$

whereas,

R_k^d = dependent resource k

$|R_k^d|$ = amount of resource k

N_k^d = set of resources being allocated

S_k^d = subgroup of resources to be allocated

k = number of resources to be allocated

$v(S)$ = utility or payoff for any subgroup S of resources

$v(N)$ = utility or payoff for N sets of resources.

For simplicity, let us consider an example of two types of resources which are dependent on each other. Resource A and resource B have to be in pair, or otherwise do not provide any benefit for the individual. For instance, if there are 5 units of resource A and 10 units of resource B, the equations of the utility of resources are as follows:

$$v(A) = v(B) = 0$$
$$v(AB) = u\left(\min\left\{\left|R_A\right|, \left|R_B\right|\right\}\right)$$
$$= u\left(\min\{5{,}10\}\right)$$
$$= u(5)$$

In other words, the utility or payoff for an individual when (s)he is provided with 5 units of resource A and 10 units of resource B are the same as that when (s)he is provided with 5 units both. Since resource A and resource B are dependent on each other, 5 of them can be set or grouped together for using while another 5 units of resource B remains and could not be utilized yet.

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[3] It should be noted that we do not consider the case that individual has a choice to sell each of resource for his/her own benefit.

[4] In this study, we classify permanent houses as independent resource, assuming that victims have no restriction about lands (i.e. each victim has an equal right to receive a permanent house). However, it should be noted that permanent houses can be also considered as dependent resources if we take land issues into account.

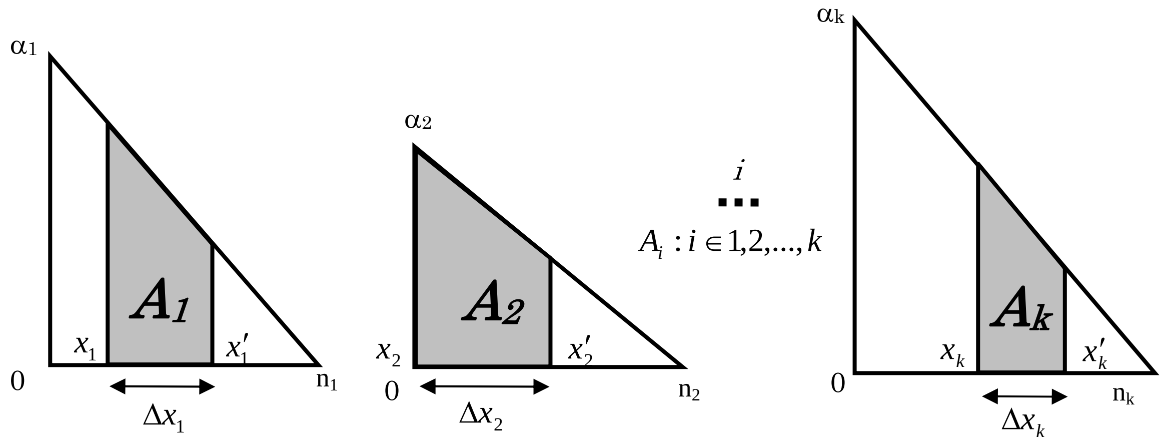

Figure 2: Individual marginal utility functions for resource optimization

In the field of natural-disaster resource management, examples of these resources are "boats and engines", "electrical generators and electrical equipments"[5], *etc*.

4 RESOURCE OPTIMIZATION MODELS

Without considering types of resources and expected increase in the utility of individual when provided with each unit of resource, those resources may not be allocated efficiently. We have developed resource optimization models to optimize the benefits to individual when provided with multiple types of resources. Generally, an individual could be one person or group of persons. In this study, each village is assigned as one unit of the individual while the whole area affected by tsunami represents the society.

Assume that one particular resource will be allocated to k individuals in the society (1 ≤ number of individual ≤ k). Marginal utility function of each individual can be shown in Fig.2.

From Fig. 2, A_1 represents the increase in the utility of the first individual when receiving the resource equal to an amount of Δx_1. Similarly, A_2 represents the increase in the utility of the second individual, when receiving the amount of resource as much as Δx_2. Finally, A_k refers to the increase in the utility of individual k after receiving the amount of particular resource equal to Δx_k. Normally, the total number of resource to be allocated by the provider should be more than or equal to the summation of resources allocated to individuals.

To optimize the resources, two resource allocation theories, utilitarian theory and egalitarian theory, are employed. For the utilitarian theory, we consider maximizing the summation of increase in the utility of all individuals in the society; while the egalitarian theory pays more attention to the individual who is worse off in the society by maximizing the total area under marginal utility function of each individual, starting from the worst, second-worst, and the other respectively. Two different resource optimization models for each type of resource are described as follows.

4.1 Independent Resource Optimization Model

Resource C is assumed to be an independent resource. Marginal utility function of independent resource (Fig. 3) is developed by modifying the

[5] Electrical generators are necessary when considering the locations without electricity such as far island and the places seriously destroyed by disaster.

generic marginal function (eq. 1).

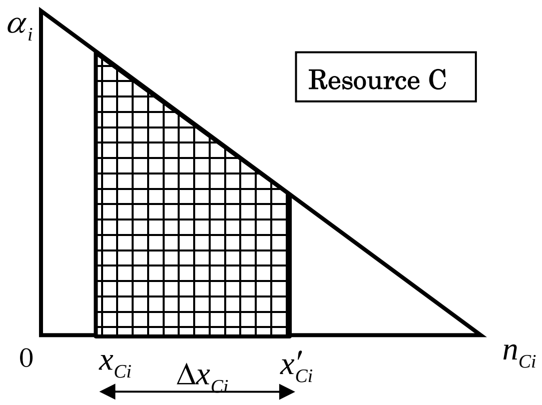

Figure 3: Marginal utility for resource C

Utilitarian-based resource optimization model can be developed as shown in eq. (8).

$$\underset{\Delta x_{Ci}}{Max} \sum_i u_{Ci}(x_{Ci})$$

$$\underset{\Delta x_{Ci}}{Max} \sum_i \alpha_i \Delta x_{Ci} \left(1 - \frac{x_{Ci}}{n_{Ci}} - \frac{\Delta x_{Ci}}{2n_{Ci}}\right) \tag{8}$$

$$s.t. \quad \sum_i \Delta x_{Ci} \leq X_C$$

$$\Delta x_{Ci} \geq 0$$

Egalitarian-based resource optimization model can be developed as shown in eq. (9).

$$\underset{\Delta x_{Ci}}{Max}\, Min\{u_{C1}(x_{C1}), u_{C2}(x_{C2}), \ldots, u_{C3}(x_{C3})\}$$

$$\underset{\Delta x_{Ci}}{Max}\, Min\left\{\alpha_i \Delta x_{Ci} \left(1 - \frac{x_{Ci}}{n_{Ci}} - \frac{\Delta x_{Ci}}{2n_{Ci}}\right)\right\} \tag{9}$$

$$s.t. \quad \sum_i \Delta x_{Ci} \leq X_C$$

$$\Delta x_{Ci} \geq 0$$

whereas,

x_{Ci} = amount of resource C held by individual *i* before the allocation

Δx_{Ci} = amount of resource C allocated to individual *i*

n_{Ci} = total need of resource C by individual *i*

α_i = comparison parameter of individual *i*

4.2 Dependent Resource Optimization Model

Dependent resource optimization model is developed based on the characteristics of resources that need to be together for the usability. We assure that the benefits of this type of resources will be increased only when the resources are put in a group, otherwise the benefit of subgroup of the resources is considered to be zero.

For simplicity, let us consider an example of two types of resources which are dependent on each other. Resource *A* and resource *B* have to be in pair, or do not provide any benefit for the individual. The marginal utility of these resources can be modeled as shown in Fig. 4 and Fig.5.

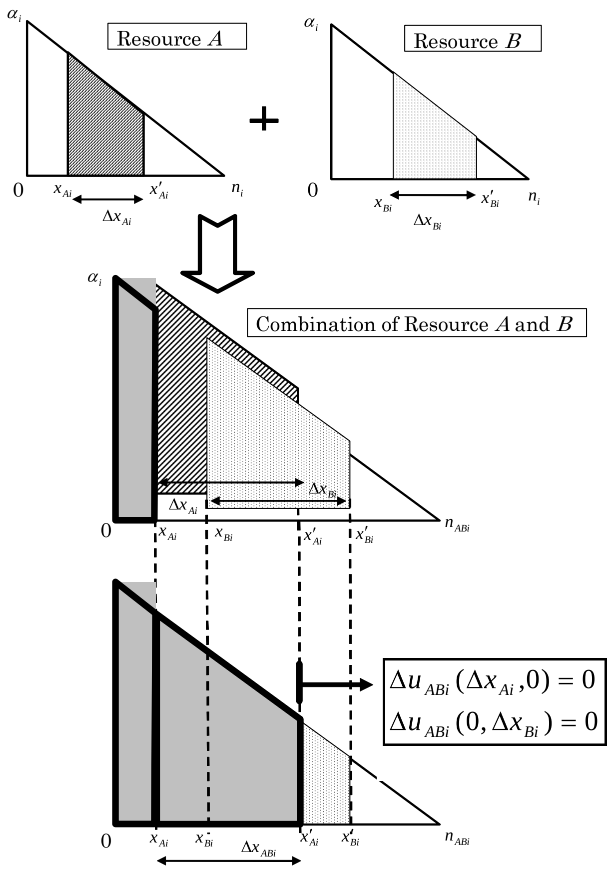

Figure 4: Combination utility between resource *A* and resource *B*

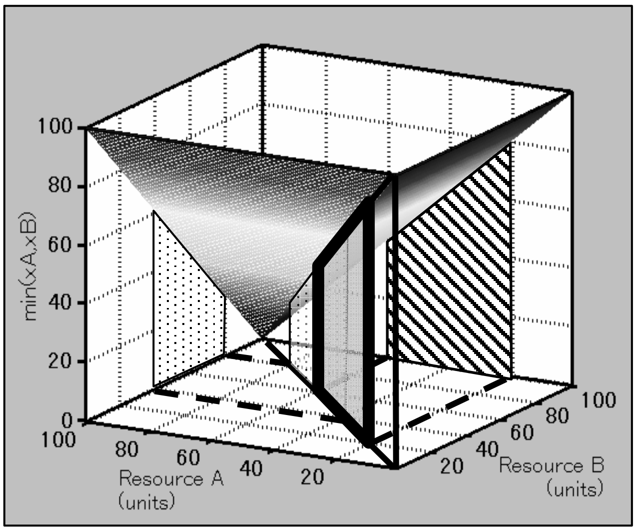

Figure 5: Combination utility between resource *A* and resource *B* shown in 3-Dimension

Marginal utility function of dependent resource as the function of resource *A* and resource *B* are modified from eq. (1) and developed as follows:

$$u_{ABi}(\Delta x_{Ai},\Delta x_{Bi}) = \frac{1}{2}(\Delta x_{ABi})\left[\alpha_i\left(\frac{n_{ABi}-\min(x_{Ai},x_{Bi})}{n_{ABi}}\right) + \alpha_i\left(\frac{n_{ABi}-(\min(x_{Ai},x_{Bi})+\Delta x_{ABi})}{n_{ABi}}\right)\right]$$

$$= \frac{1}{2}(\Delta x_{ABi})\left[\alpha_i\left(\frac{2n_{ABi}-2\min(x_{Ai},x_{Bi})-\Delta x_{ABi}}{n_i}\right)\right]$$

$$= \frac{1}{2}(\Delta x_{ABi})\left[\alpha_i\left(\frac{2n_{ABi}-2\min(x_{A},x_{B})-\Delta x_{ABi}}{n_{ABi}}\right)\right] \quad (10)$$

Following the utilitarian-based theory, social welfare of the victims can be optimized by maximizing the summation of utility of each individual. By substituting the marginal utility function (eq. (1)), the objective function of resource optimization model is shown in eq. (11).

$$\underset{\Delta x_{Ai},\Delta x_{Bi}}{Max} \sum_i u_{ABi}(\Delta x_{Ai},\Delta x_{Bi})$$

$$\underset{\Delta x_{Ai},\Delta x_{Bi}}{Max} \sum_i \frac{\alpha_i \Delta x_{ABi}}{2}\left(\frac{2n_{ABi}-2\min(x_A,x_B)-\Delta x_{ABi}}{n_{ABi}}\right) \quad (11)$$

$$\begin{aligned} s.t. \quad & \sum_i \Delta x_{Ai} \le X_A \\ & \sum_i \Delta x_{Bi} \le X_B \\ & \Delta x_{Ai} \ge 0 \\ & \Delta x_{Bi} \ge 0 \end{aligned}$$

In the case of egalitarian-based theory, total utility of the worst off individual in the society is maximized. The objective function of resource optimization model is shown in (eq. (12)).

$$\underset{\Delta x_{Ai},\Delta x_{Bi}}{Max}\ Min\{u_1(\Delta x_{A1},\Delta x_{B1}),u_2(\Delta x_{A2},\Delta x_{B2}),...,u_i(\Delta x_{Ai},\Delta x_{Bi})\}$$

$$\underset{\Delta x_{Ai},\Delta x_{Bi}}{Max}\ Min\left\{\frac{\alpha_i \Delta x_{ABi}}{2}\left(\frac{2n_{ABi}-2\min(x_A,x_B)-\Delta x_{ABi}}{n_{ABi}}\right)\right\} \quad (12)$$

$$\begin{aligned} s.t. \quad & \sum_i \Delta x_{Ai} \le X_A \\ & \sum_i \Delta x_{Bi} \le X_B \\ & \Delta x_{Ai} \ge 0 \\ & \Delta x_{Bi} \ge 0 \end{aligned}$$

$$\Delta x_{ABi} = \min(x_{Ai}+\Delta x_{Ai}, x_{Bi}+\Delta x_{Bi}) - \min(x_{Ai},x_{Bi}), \quad (13)$$

whereas,

x_{Ai} = amount of resource A held by individual *i* before the allocation

x_{Bi} = amount of resource B held individual *i* before the allocation

Δx_{Ai} = amount of resource A allocated to individual *i*

Δx_{Bi} = amount of resource B allocated to individual *i*

n_{ABi} = total need of resource *A* and resource *B* requested by individual *i*

α_i = comparison parameter of individual *i*

5 AN EXAMPLE OF THE UTILIZATION OF RESOURCE OPTIMIZATION MODELS FOR MANAGING CONFLICT IN RESOURCE ALLOCATION

Resource optimization models developed in previous sections could be embedded in the decision support system for helping decision making generate fair resource allocation. In this study, we integrate these models in the post-disaster decision support system, called ViTSPRA[6] (Visualization Tool for Spatial Resource Allocation) (Suwannachote and Horita, 2006a; Suwannachote and Horita, 2006b); and then examined in the case study of tsunami affected area in Phang Nga, the most seriously damaged province in Thailand. Need and aid data used for the analysis has been collected from 119 villages (3759 victims) and 74 aid agencies, respectively. The resources considered in this case study are: boats and engines, permanent houses, and funding support for education of children.

We have classified boats and engines as dependent resources whereas permanent houses and funding support for education of children as independent resources. The results analysis of resource optimization model has been shown compared to the existing approach (Table 1 and Table 2).

Table 1 Comparison of the spatial utility for utilitarian resource allocation schemes

Resource Type	Social Welfare (Summation of Marginal Utility)	
	Without System	*Utilitarian-Based*
Boats and Engines	94	197
Permanent Houses	443	795
Funding for Education	36	139

[6] The prototype of this system can be accessed through URL: http://dr.chakrit.googlepages.com (last date updated: 22/11/06)

Table 1 compared the utilitarian social welfare between the resource allocation schemes generated by the system and the existing resource allocation scheme. The utilitarian-based resource optimization model has shown that the summation of marginal utility of victims in the affected area could have been better by following the schemes suggested by the proposed model

Table 2 Comparison of the spatial utility for egalitarian resource allocation schemes

Resource Type	Social Welfare (Minimum TU/MTU*100)	
	Without System	*Egalitarian-Based*
Boats and Engines	0%	75%
Permanent Houses	0%	0% → (91%)
Funding for Education	0%	63%

**TU = Total Utility; MTU = Maximum Total Utility*

Table 2 compared the egalitarian social welfare between the resource allocation schemes generated by the system and the existing resource allocation scheme. For the sake of comparison, we have shown these in terms of percentage between total utility of each village after receiving resources and the maximum total utility (i.e. the total utility if that particular village has been allocated with total amount of need). The egalitarian-based resource optimization model has shown that that the minimum utility of victims in affected area could have been at least as good as the existing approach if following the schemes suggested by the proposed model.

It should be noticed that when employing egalitarian-based resource optimization model, the egalitarian social welfare that arises from the permanent house is also equal to 0%. This situation occurred to *Ban Nam Khem*, a village located in

Takua Pa district, Phang Nga province. Since this village faced serious damages and lost many more houses compared to the others, the marginal utility of this village after receiving one unit of permanent house may be more than that of other villages (refer to eq.(1) and eq.(2)). Therefore, according to the maximin rule of egalitarian theory, Ban Nam Khem may have lower priority to receive the resource. Note that this model, however, make the second worst village has the social welfare as much as 91% which claimed that permanent houses are allocated to other villages. Though, this may be the limitation of egalitarian-based resource optimization model, one of the solutions could be to consider the villages which are seriously damaged separately.

6 CONCLUSIONS

Without cooperation among aid agencies, resource allocation schemes might be inefficient. It has been examined in the case study that aid agencies could have provided better benefit for the victims if the resources had been optimized.

This paper has proposed a new resource optimization model for avoiding resource allocation conflict in the field of natural disaster management. Two well-known resource allocation theories have been employed in this paper – utilitarian and egalitarian. We have also developed models by considering the characteristics of resources whether they are independent or dependent with others.

Finally, the resource optimization models developed in this study have been examined in the case study of tsunami affected area in Phang Nga. By employing the resource classification concept and resource allocation theories, this new model could help to improve the efficiency of resource allocation scheme by increasing social welfare of victims.

One important limitation of this model is that it has concentrated on the village level as an analytical unit of individual. Therefore to address the equity issue after the resource is allocated to each village is still needed for further study. Another customization of the model may be done by employing the mixed resource allocation theory. More criteria as to how resources are allocated could be added to the models, for example, the minimum level of utility for each individual, classification of victims by their jobs such as fishermen, farmer, *etc*. The issue of the aggregation of marginal utility by different types of resources is also a great challenge.

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