Agent-Based Model for Demand Management in Relief Distribution

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Agent-based model (ABM) for planning the relief distribution after large scale disaster is presented. The focus is on the selection of resource-allocation, i.e. the selection of demand point based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method and the selection of logistics component i.e. truck-composition, number of distribution center. These planning tasks, which in practice are usually carried out by different stakeholders in humanitarian logistics (HL), are assigned to different agent types. A further agent, the coordinator agent, is responsible for combining the local sub-plans into an overall plan in such a way that relief distribution can attain the objectives of HL i.e. delivering right product at right place at right time at right cost. We have proposed noble framework of 'acknowledge' to integrate all agents in the ABM. The ABM is tested using the great east earthquake relief distribution problem instances with different logistical resources composition. We have also generated random data to analyze the robustness of the model, in particular to the truck composition and logistical cost. In addition, the result highlighted that urgency based distribution system can produce more social satisfaction compare with random distribution system.

Key Words : *agent-based model, relief distribution, demand management, TOPSIS, last mile distribution*

1. INTRODUCTION

Humanitarian logistics (HL) aims to provide relief (in the form of water, food and shelter) to the right person, in the right time, the right product and by the right cost. The major difficulty of achieving efficient HL is mismatch between large demand and limited supply. Demand management become inevitable for better use of available relief in ‘cost-effective’ manner. The measure of cost-effectiveness in in corporate logistics is rather straight-forward. Suppliers in corporate logistics receive revenue from the customer and can evaluate profit-and-loss account. On the other side, Aid-organizations in humanitarian logistics play similar role of supplier in corporate logistics. Aid-organizations (relief-suppliers) do not receive monetary revenue after delivering relief to victims. Therefore, the computation of profit-and-loss account in HL becomes difficult. Lately, need of evaluation of cost-effectiveness gain attentions for aid-organizations accountability[1)]. We introduce an indicator ‘acknowledge’ for proxy of profit-and-loss account for aid-organization.

Herewith, HL engages several stakeholders in different stages of relief-flow. Typically, no single actor has sufficient resources to respond effectively to a major disaster[2)]. Stakeholders depend on each other even though they may have different interests, mandates, capacity, and logistics expertise[3)]. The evaluation of profit-and-loss requires including stakeholders interests. This study proposes an agent-based model (ABM) for demand management with multiple stakeholder interests.

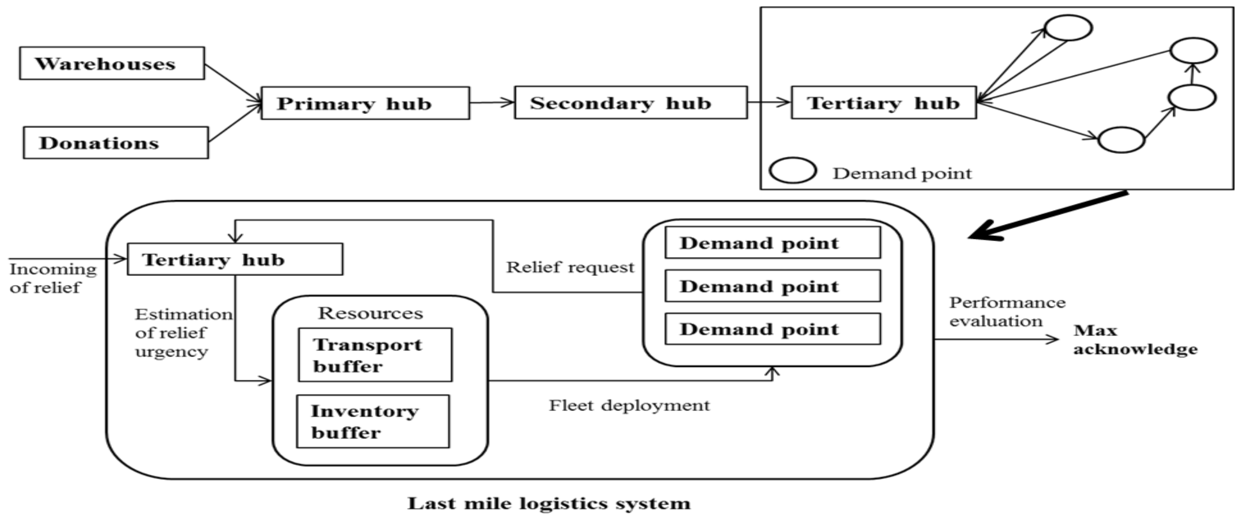

Fig. 1 Supply chain of HL and task chains in LMD

The relief chain has several stages as shown in Fig. 1. Relief transfer from various locations to a primary warehouse, next reliefs are shipped to secondary hub. At the secondary hub, reliefs are stored, sorted and transferred to tertiary hubs. Finally, tertiary hub delivers relief to demand-points (victims). The relief distribution from tertiary hub to demand point is the most challenging, known as last mile distribution (LMD), and requires special attentions. The need of transportation management and demand management create difficulties in LMD[4]**.** For this reason, they form the focus of this paper which introduces an agent-based model for the relief distribution in LMD. To make the focus clear, the task chains that are linked to demand management is outlined in Fig. 1. It shows that, reliefs are received in tertiary hub from secondary hub. Simultaneously, demand points place requests for relief to tertiary hub. Along this, tertiary hub evaluates the relief request under the resource constraints and deploys relief to the demand point. Finally, the whole system performance is evaluated with the aim of minimizing deprivation cost.

We introduce the application of ABM in HL. This approach is highly suitable for dynamic situations and can provide good solution. Note that a simulation model is only a tool that can help emergency logistics decision makers better understanding the dynamics within an emergency response. A decision maker wants to know the model behavior if it is going to be implemented. This can be done through the development of agent-based model. This option is much less risky than actually waiting for another earthquake (or another disaster) to happen and test the developed emergency response model in a real-life situation.

This model allows actors to investigate the effects of transport measures as well as to understand the mechanisms of demand management in the dynamic environment. The reminder of the paper is structured as follows. In the next section, we explore the stakeholders in HL and their activities and objectives. This section also introduces the architecture of ABM for coordinated relief-distribution and deployment strategies. In section 3 the proposed model, is evaluated using randomly generated test instances. We end up with conclusions, and summarize the outcome of this research.

2. METHODOLOGY

Consider a large scale earthquake has contributed to different degrees of damages. Relief needs to be distributed to the victims based on relief urgency subject to stakeholders' interests. In this section, we define our proposed measure '*acknowledge*'. After that, this section explains the relevant stakeholders who aim to provide assistance to victims. It illustrates architecture of ABM, and operation of ABM.

(1) Defining Acknowledge

Just as commercial logistics, aid-organizations compete to generate more funds from its market. Donors donate fund to gain satisfaction by '*doing good*' for society. The market for aid-organizations is called philanthropic market where three basic categories of donors (individuals, corporations and foundations) exist. Total donation of a aid-organization is modeled as positive function of social benefits generated by the organization and efficiency of the organization[5]:

$$D = D[SB(x), E] \quad D_{SB} > 0, D_E > 0 \tag{1}$$

Where
D = the aggregate supply of donations
$SB(x)$ = social benefit from x unit available resources
E = the efficiency of the organization

Of course, the sensitivity of donations to these two factors differs across different types of donors. Social benefits are often intangible, hard to quantify, and difficult to attribute to a specific organization. Fortunately, social benefit for distributing relief can be linked with deprivation cost which represents the shortage relief. It can be reasonably assume that

$$SB(x) = supplied\_relief \times unit\_value\_of\_supply \quad (2)$$

$$dc = \mu \times n \times unit\_cost\_of\_relief\_shortage \quad (3)$$

$$n = demand\_relif - supplied\_relief \quad (4)$$

Where

dc = deprivation cost

μ = relief urgency

Now, efficiency refers to "Whether a given effect [is] produced with least cost or, alternatively, whether a given amount of resources [is] used in a way to achieve the greatest result[6]**"**. So assessment of efficiency, therefore, requires measurements of both resources and system outcomes or result.

From a purely economic point of view, relief efforts are assessed by the value of Eq. (5) Here, the term is named 'acknowledge'. All other thing being equal, a relief effort is more efficient to the extent that it reduces the social cost more.

$$acknowledge = \frac{donation}{deprivation\_cost} \quad (5)$$

The aid-organization that creates the most *D[SB(x),acknowledge]* by providing relief will garner more donations, whereas those that squander their resources will suffer lower future donations[7]. Lily Duke, for instance, an independent film producer, arrived in New Orleans with a single fleet-load of donated food. The efforts were highly acknowledged. Within three months of the disasters onset, Duke was operating three distribution centers that served twenty thousand people a day[8]**.** In the context of humanitarian logistics, acknowledge tell aid-organization whether or not relief – are efficiently fulfilling disaster victims' demand.

(2) Stakeholders

Donors donate fund to aid-organization with the trust of higher utilization of fund**.** Kotle[9] explains that donors expect in exchange of donation. He continues, "*Exchange is the central concept underlying marketing. It calls for the offering of value to another party in exchange for value*". According to Cermak et al.[10]**,** the 'exchange value' in philanthropic market represents social esteem. Aid-organizations want to generate more funds by gaining trust of donors.

The stakeholders are aid-organization, carrier, demand agent, and society (e.g. national authority, evaluation team, media etc.). Fig. 2 shows objective and activities of each stakeholder and details are provided as follows.

Aid-organization agent (AOA): AOA is key player in humanitarian logistics. AOA includes the non-profit organization (npo) (for instance, International Federation of Red-cross and Red-crescent, World Vision International, and Care) who collects fund from donors and provide humanitarian assistance to victims. Aid-organizations compete to generate trust of donors and for collecting fund. Aid-organization aims to maximize 'acknowledge' by effective relief distribution strategy. In our model, AOA is assigned for the job of tertiary hub and make plans for relief distribution.

Carrier agent (CAA): Carriers follow the behavior of business logistics and want to maximize monetary value. Monetary profit is the driving force for carrier. They perform several activities such as transporting, loading, and unloading. The goals of carriers are transport cost reduction, and waiting time reduction.

Demand agent (DA): DA is assigned in a demand point and is the last key stakeholder in the supply chain. DA receives relief from tertiary hub and distribute to victims. DA assigned for demand estimation, ordering goods, receiving goods, and distributing goods to victims. DA has objectives of bringing more reliefs and it is thus a very local-specific (i.e. selfish) behavior.

Society agent (SA): SA does not have decision making power on relief-chain. SA evaluates performance value for aid-organizations' efforts and assigns 'acknowledge' value for relief distribution. SA is a representative of evaluation team

Coordinator agent (COA): COA is responsible to coordinate the all relief flow. It is a hypothetical agent in the model.

(3) Architecture of Agent-Based Model

The relief distribution includes a series of decisions including selection of DA, delivery time, and fleet composition. The following details apply to simulation system

- Two types of product, namely product1 and product2 are modeled here. The first is the daily consuming relief including water and meal box, and the second is the daily-used equipment for refugees e.g. sleeping bags and camps[11, 4]. One vehicle can carry one type of product at once.

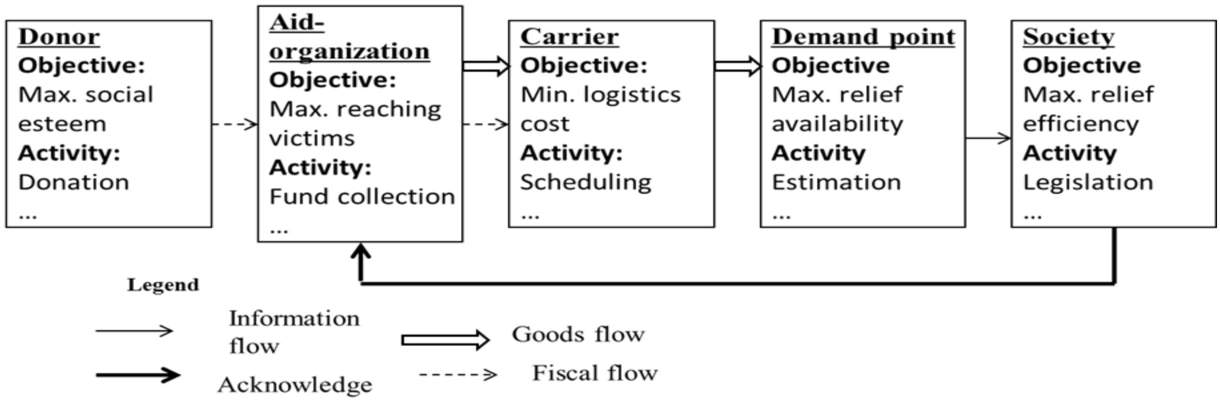

Fig. 2 Stakeholders' ontology of humanitarian logistics

- Demand point places order for relief to tertiary hub. And tertiary hub faces the resources constraint to meet the request of all demand points
- Fleet operation has limited operational time and it is eight-hour shift. A fleet incurs loading time at tertiary hub and unloading time at demand point. The loading time and unloading time will be longer in case of more fleet at the current position of subject fleet.
- For the purpose of planning transport operation, the cost incurred for each delivery is computed using Eq.(6). As the times required de facto for loading on fleet, transport to next destination, waiting time at destination, unloading from fleet, and return to origin.

$$LC = 2\xi TT + \zeta(LT + UT + WT) \quad (6)$$

Where, *LC*, *TT*, LT, UT and WT are logistics cost, transport time, loading time, unloading time, and waiting time respectively. ξ and ζ cost per unit time.

Fig. 3 represents the relationship among agents. ABM allows assigning a specific type of agent to each of the problem of relief distribution. While transportation is managed over the whole planning period by a single agent, named as carrier agent

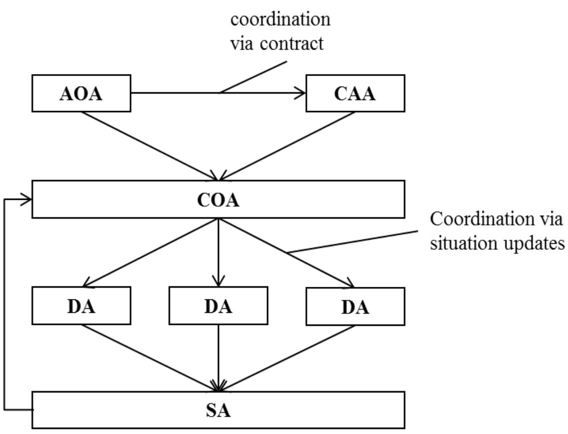

Fig. 3 Architecture of agent based model

(*CAA)*, demand points are distributed among demand agent (DA: $DA_n=1,\ldots,n$) . DA is responsible for only one demand point and can't exchange information each other.

Aid-organization agent (AOA) makes contract with CAA. Coordination of local planning of the individuals DA, AOA and CAA is taken over the coordinator agent (COA). Hence, AOA provide the fleet composition plan to COA. The relationship of AOA and COA is client/server concept. In the role of a client, the AOA submits a resource plan and the COA returns the solution to the AOA.

The task of COA depends on the simulation environment. In this research, we have implemented two simulation environments.

- The first problem class, designated 'uncoordinated' is based on the situation where reliefs are distributed in the aim of minimizing distribution cost.
- The second problem class, designated "global coordination" where victims severity, damaged condition are included with logistics cost.

Finally society agent (SA) evaluates the performance of the logistics system by using urgency based mechanisms and submits to COA.

(4) Operation of Agent-Based Model

Fig. 4 represents steps in the simulation and the model runs until it meets termination criteria.

In phase (1) AOA submits plan of fleet composition and inventory.

In phase (2) the relief distribution to demand point is carried out in six steps. In step (2.1) CAA submit cost information to COA using Eq.(6)

In step (2.2) DA estimates the demand adopting the method proposed by Sheu[11].

for product1

$$D_l^i(t) = \max\{a_1 \delta_i(t)\bar{L} + z_{1-\alpha}\sigma_{1i}(t)\sqrt{L} \quad 0\} \quad (7)$$

for product2

$$D_i^i(t) = \max\{a_2\,\delta_i(t) + b_{2i} - \sum_{\in=1}^{t-1} c_{2i}(t-\varepsilon) \quad 0\} \tag{8}$$

Where a_1 and a_2 are the parameters representing the average hourly demand of each product and b_{2i} corresponding buffer demand associated with product2 and affected area *i*. $c_{2i}(t\text{-}\varepsilon)$ represents the time varying amount of product2 arriving at a given affected area *i* in a given interval of $(t\text{-}\varepsilon)$. $\overline{L}$ represents upper bound preset to regulate the temporal headway between two successive relief distribution to any given affected area without exceeding corresponding maximum value. $Z_{1-\alpha}$ represents the respective statistical value given that the tolerable possibility of time varying relief demand shortage is set to be α; $\delta_i(t)$ represents the estimated number of victims in affected area *i* in a given time interval *t*. $\sigma_i(t)$ represents time varying standard deviation of relief demand associated with delivered relief and affected area *i*. which is given by

$$\sigma_i(t) = \frac{\sqrt{\sum_{\in=0}^{t-1}[d_{1i}(t-\varepsilon) - \overline{d}_{1i}(t)]^2}}{t-1} \tag{9}$$

where $\overline{d}_{1i}(t)$ represents the time-varying mean value with respect to the time varying demand $d_{1i}(t)$ and it is given by

$$d_{1i} = \frac{a_1 \sum_{\in=0}^{t-1} \delta_i(t-\varepsilon)}{t} \tag{10}$$

In step (2.3), AOA collects information from DAs for creating hierarchy of demand points. AOA aims to minimize the difference in the satisfaction rate (SR) between nodes[12]. The satisfaction rate is the ratio between the requested demand and the actual delivered amount and calculated as

$$SR_i = \frac{\sum_j \sum_t x_{ijt}}{\sum_j \sum_t d_{jt}} \tag{11}$$

Where, x_{ijt} is amount of item *j* delivered to node *i* in period *t* and d_{jt} is the demand of the item *j* during period *t*.

In step (2.4) COA creates joint evaluation matrix after incorporating information of AOA and CAA and deploy relief to demand point. In step (2.5), COA deploys the fleet to the DA. In step (2.6), the fleet returns to tertiary hub. In this step, simulation can run in two different ways

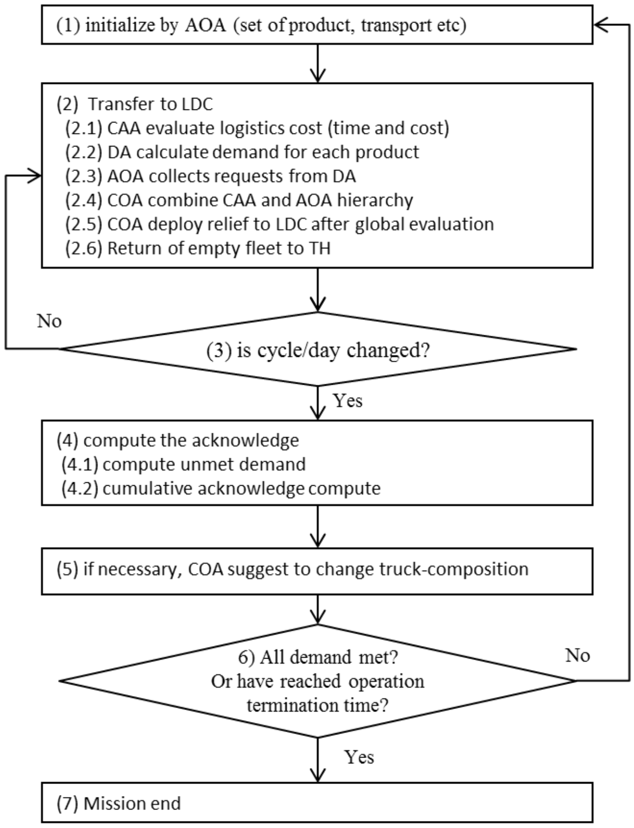

Fig. 4 Simulation flow of agent-based model

Case 1. the deployment decision maker is AOA and the simulator will select the tertiary hub which have lower level of inventory.

Case 2. The deployment decision-maker is COA who evaluate the inventory-status and also logistics cost. For example, waiting time at tertiary hub depends on presence of other fleet which will be ignored in case 1 and case 2.

Phase (3) is a logical condition where COA checks the status of work. Here, planning-period is 10 days (cycle) and phase (4) performs once in every cycle.

Phase (4) is the performance evaluation of the system. SA evaluates performance of the system based on the technique for order of preference by similarity to ideal solution (TOPSIS)[13,14]. TOPSIS method is as follows

A set of demand agent (DA_n= *1,…, n)* to be compared with respect to a set of the criteria $C=\{C_j, j=1,\ldots, m\}$; therefore an assessment matrix for the problem can be obtained as

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nm} \end{bmatrix} \tag{12}$$

Six criteria are selected for making hierarchy of demand points. Those criterions are as follows

C1. time varying demand for product1.
C2. time varying demand for product2.
C3. the population density associate with a given affected area.
C4. the ratio of frail population, e.g. children and older.
C5. the time difference between present time and last delivery.
C6. the restoration progress of area. This value lies within 1 to 10.

It is worth to note that the weight of each criterion is calculated internally and the method is shown below.

Each criteria mentioned above having different scale are normalized as

$$p_{ij} = \frac{P'_{ij}}{\sum_{i=1}^{n} P'_{ij}}, \quad i = 1, \ldots, n \tag{13}$$

Next, each criteria weight in Eq. (12) can be measured by the entropy value e_j (Deng et al. 2000) as

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij} \tag{14}$$

Here $k = \frac{1}{\ln n}$ is a constant. It ensures $0 \leq e_j \leq 1$

The degree of divergence (d_j) of the average intrinsic information contained by each criterion C_j ($j = 1, \ldots, m$) is calculated as

$$d_j = 1 - e_j \tag{15}$$

the objective weight for each criterion C_j ($j = 1, \ldots, m$) is thus given by

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{16}$$

After determining rating of the criterion, the next step is to aggregate them to produce an overall relief-urgency for each zone. The aggregation process is based on the positive ideal solution (A^+) and the negative ideal solution (A^-) which are defined, respectively, by

$$A^+ = \left(\max_i (p_{i1}), \ldots, \max_i (p_{im}), \right) = p_1^+, \ldots, p_m^+ \tag{17}$$

$$A^- = \left(\min_i (p_{i1}), \ldots, \min_i (p_{im}), \right) = p_1^-, \ldots, p_m^- \tag{18}$$

From Eq. (12), (17) and (18), the weighted Euclidean between A_i and A^+, and between A_i and A^- are calculated, respectively, as

$$d_i^+ = \sqrt{\sum_{j=1}^{m} w_j (p_j^+ - p_{ij})^2} \tag{19}$$

$$d_i^- = \sqrt{\sum_{j=1}^{m} w_j (p_{ij} - p_j^-)^2} \tag{20}$$

Where i=1, . . . , n and j=1, . . . , m

An overall relief urgency of each zone is thus computed by

$$\mu_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{21}$$

The larger the index value, the more urgent of the zone.

In step (4.2), the value of 'acknowledge' is calculated. Holguin-Veras et al.[15)] propose a methodology of calculating deprivation cost. In this formulation, we have incorporated the relief-urgency. Then deprivation-cost is

$$f_i(\Delta t) = \mu_i \, n_i(t) \, e^{\gamma + \beta \Delta t} \tag{22}$$

Where

Δt = time gap between two deliveries,
$n_i(t)$ = un-met relief demand at time
γ and β = parameter
μ_i is the urgency factor

The system aims to minimize the deprivation cost. Then, Eq. (23) gives the value of acknowledge

$$acknowledge = \frac{donation}{deprivation\_\cos t} = \frac{donation}{\sum_{i=1}^{n} f_i(\Delta t)} \tag{23}$$

In phase (5), COA suggests AOA to change the fleet composition in the aim of minimizing deprivation cost. After meeting all demand or meeting stopping criteria, the operation terminates.

In phase (6) model checks the termination criteria. If termination criteria is satisfied, the mission ends.

3. EMPIRICAL STUDY

The ABM has implemented in open-source tool NetLogo which allows the user to explore the parameter system in systematic way and tested on Intel (R) Core (TM)i3-3220 @3.30 GHz PC. The test concept applied and the results achieved are described in the following.

(1) Case Study

The 'Great East Japan earthquake' destroyed an untold number of roads and buildings. The most severely affected prefectures are Fukushima, Miyagi, and Iwate having population before disaster 2.35 million, 1.33 million and 2.03 million respectively. In the case study, we have collected data for five most affected cities in three prefectures. A number of shelters are established in prefectures. Miyagi prefecture lost 3.11% (in number 10,739) of its population to the disaster. The number of fatalities in Iwate prefecture is fewer than Miyagi. However, Iwate lost 4.35% of its population. Fukushima faced mush smaller number of fatalities[16, 17]. Table 1 shows the victims in shelters, fatalities, frail population and density for the five most impacted cities in each prefecture. ABM model is applied to distribute relief among the shelters. Here, shelters are the demand points. The two problem classes were selected as follows:

- The first problem class, designated ‘transport composition’ is based on the situation where fleet composition is changed.

Table 1 Fatalities in five cities of three prefectures

City	victims in shelter	%Fatalities	frail	Density (people per km^2)
Iwaki	341983	0.1	0.065	270
Namie-machi	18866	0.97	0.065	99
Minamisoma	69171	1	0.065	170
Soma	37843	1.21	0.0658	190
Shin-chi-machi	7141	1.58	0.0658	191.3
Natori	69311	1.47	0.06	727
Higashimat-sushima	35522	3.32	0.060	420
Ishinomaki	160835	3.65	0.060	295
Mina-mi-sanriku	16294	2.3	0.060	120
Kesennuma	63841	7.4	0.060	220
Rikuzentaka-ta	21262	10.03	0.067	100
Kamaichi	41360	3.03	0.067	92.9
Otsuchi	13811	11.63	0.067	83
Yama-da-machi	16959	4.98	0.067	77
Miyako	57406	1.34	0.067	46

- The second problem class, designated ‘physical network’ is based on the situation where number of tertiary hubs is changed.

For the base case, network consists of 3 tertiary hubs, 15 demand points. Transport composition contains 12 fleet among them 6 carry product1 and remaining 6 carry product2. For each of the two problem classes, 5 problem instances were generated. The following details apply:

- For every instance of problem class, the transport composition lies between 75% and 250% of total demand points. The fleet composition 9, 12, 15, 18, 21, 24, 27 and 30 are used.
- For each problem instances, the fleet number is fixed and defined it before simulation start.

From the point-of-view of the decision-makers, the value of the global objective functions that can be achieved through the use of ABM is major interest. In addition, however, the decision-makers are also interested in the robustness of solution with regard to changes in problem data. Finally, from more strategic point of view, the question of how many tertiary hubs should permanently build is also an interest. These aspects and the questions are considered in the followings

(2) Results

The case study is computed using the coordinated method and the un-coordinated method. In the coordinated method, model follows the simulation flow stated in Fig. 4. On the other hand, un-coordinated method skips the step 2.4 of phase 2 in Fig. 4. In this case, DA is selected randomly.

Deprivation cost, transport cost and acknowledge value are calculated by changing the composition of fleet and number of tertiary hubs. For the purpose of comparison of two methods 18 simulation run are carried out and is presented in Table 2. In order to examine the solution behavior of ABM and the embedded relief distribution methods for different relations between transport cost and deprivation cost, different number of fleet are introduced.

According to Table 2 coordinate method dominates the uncoordinated method for all number of fleet compositions. The deprivation cost reduction in the value of Eq. (22)for 9 fleet with 3 hubs and 85% for 30 fleet with 3 hubs. Similar improvements are observed in in the4 hubs composition.

In contrast, the change of transportation cost is not large. The coordinate method gains in transportation cost 2.7% for 9 fleets with 3 hubs and loses 0.65% for 30 fleets with 3 hubs. It implies that un-coordinate method deploy fleets to the demand points without evaluating all demand points. The use of simplified transport cost comparison definitely impairs the

Table 2 Comparison of costs of the solution method

fleet num.	distribution method	deprivation cost		transportation cost	
		3 hub	4hub	3 hub	4hub
9	coordinate	90.7	80.2	32.9	32.0
	un-coordinate	187.8	152.9	33.8	30.8
12	coordinate	70.8	61.3	43.7	42.7
	un-coordinate	169.2	126.0	42.0	43.7
15	coordinate	58.6	50.9	51.3	53.8
	un-coordinate	182.5	132.1	52.8	51.1
18	coordinate	45.7	38.8	63.8	65.0
	un-coordinate	171.9	119.2	68.5	64.9
21	coordinate	39.1	33.3	76.4	70.6
	un-coordinate	139.9	113.4	75.5	76.2
24	coordinate	30.8	27.0	85.9	81.3
	un-coordinate	135.5	102.1	88.9	87.1
27	coordinate	26.5	21.3	97.3	91.1
	un-coordinate	134.9	99.4	95.4	98.6
30	coordinate	22.3	17.1	107.8	107.7
	un-coordinate	155.5	91.4	107.7	103.1

solution quality of the model. The total transport cost is calculated using the distance traveled in the simulation multiplied by 0.02 units per km. Again, the increment of number of hubs has effect on decreasing in the value of Eq. (22). The average improvement of increasing one hub is approximately 15%.

The acknowledge values are also computed using Eq. (23) and are shown in Fig. 5. It shows that higher acknowledge values can be achieved in coordinate method. It implies that relief delivery to the person who need most create higher acknowledge value. In order to able to demonstrate the robustness of the approach with regard to changes in the problem data, Fig. 7 and Fig. 6 shows the change of transportation cost and deprivation cost for different number of fleet composition. This speaks for certain stability of so-

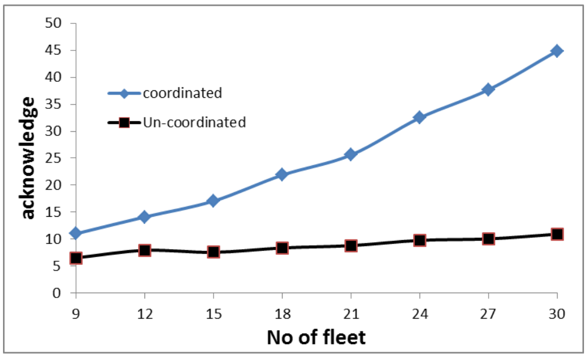

Fig. 5 Comparison of coordinated and un-coordinated distribution system with three tertiary hubs

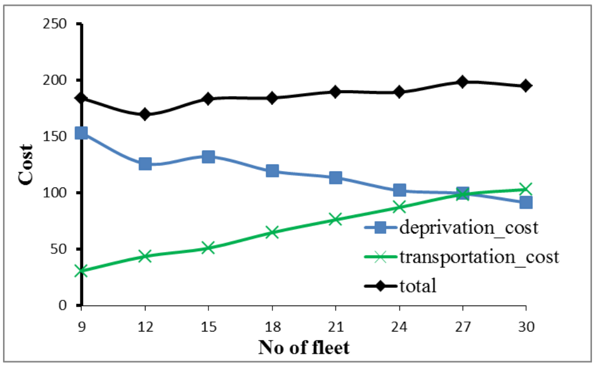

Fig. 6 Cost comparison for 4 tertiary hubs un-coordinated method

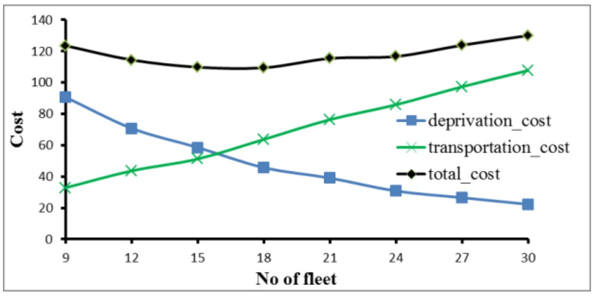

Fig. 7 Cost comparison for 4 tertiary hubs co-ordinated method

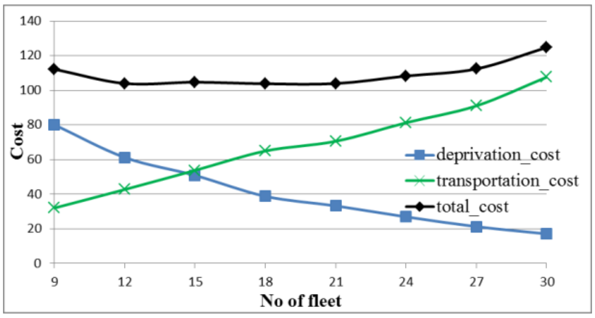

Fig. 8 Cost comparison for coordinated method (3 tertiary hubs)

lution behavior of ABM. It can be observed the total transportation cost increases with the increment of fleet and the marginal cost for each fleet remain constant marginal values of coordinated and uncoordinated methods are same. This leads to the conclusion that total available budget can be utilized efficiently using coordinated methods.

The results reported so far concern for the continuous planning of the current relief operation. The ABM can, however, also be used for supporting strategic decision making. Since relief distribution efficiency depends on the combination of number of fleet and of tertiary hubs. According Fig. 7 and Fig. 8, there always exist a cost optimum, whose position depends on conversion factor of deprivation cost to monetary value. Here it is assumed that 10 times of transportation cost. With the 3 tertiary hub network, aid-organizations can contract for 18 fleets to delivery relief for gaining minimum cost. And 15 fleet for 4 tertiary hub networks. Note that, uncoordinated method does not guarantee of minimum value. Although the conversion of deprivation cost to monetary value is a controversial issue, ABM concept presented here shows significant potential to improve the relief distribution.

4. CONCLUSIONS

Relief demand points hierarchy in especially resource shortages. The relief distribution must be planned in such a way that the deprivation cost is minimized. An additional aim is to improve the acknowledge value. To solve this problem of integrated transport operation and demand point selection, an agent-based model is proposed which covers four type of agents: aid-organization agent who make hierarchy of demand point, carrier agent who reduce waiting time, demand agent, who estimates demand quantity and coordinator agent who coordinate the local planning by the aid-organization and carrier.

The ABM is tested using Great East Japan Earthquake data. The test aims to show the benefit of alternative relief distribution method, examine the robustness of the system, and analyze the course of total relative costs of relief distribution from a more strategic point of view. The test leads to the following results:

- Coordinated method generates less deprivation cost.
- With change of fleet and tertiary hubs, the transportation cost for each fleet remains largely stable. This means that the system is, to a certain extent robust.
- In spite of controversial issue of conversion of deprivation cost, the required number of fleet decreases with the increment of tertiary hubs.

The ABM developed here seems to be suitable for supporting not only current relief response, but also the determinant of fleet contract for future relief response from a more strategic point of view.

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