A Development of Transportation Simulator for Relief Supply in Disasters

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Abstract: The Great East Japan Earthquake on March 11th, 2011 struck eastern coastal area of the Japanese main island and tsunami following the earthquake posed a devastated condition. Most infrastructures and lifelines, such as water supply systems, petroleum gas supply systems and electric power systems including Fukushima nuclear plant were damaged. Logistics systems are no exception. The authors developed “Support System for Transportation under Disaster Circumstance” comprised of three tools. This paper focuses on one of the tools, transportation simulator for relief goods and demonstrated functions of the simulator and simulation examples.

Key Words: multi agent system, simulation, transportation system, relief supply, disaster.

1. Introduction

The Great East Japan Earthquake on March 11th, 2011 struck eastern coastal area of the Japanese main island and tsunami following the earthquake posed a devastating condition. Most of infrastructures and lifelines, such as water supply systems, petroleum gas supply systems and electric power systems including Fukushima nuclear plant were damaged. Logistics systems were no exception. Highways as trunk routes connecting damaged areas and the other major cities in Japan collapsed. The tsunami following the earthquake damaged not only seaports but also entire small cities and airports facing the Pacific Ocean. It is reported that more than 400 thousand people in the damaged area were made to spend in evacuation centers as refugee. However, information of necessary relief goods was limited due to network overloads or shortage of battery of communication devices. The situation that the relief goods were not delivered to the refugees in the disaster site emerged as a social issue.

Recently many publications relevant to the logistics under disaster situation were presented [1]–[5]. However the heart of the studies was optimization techniques for logistics under disaster circumstances. Meanwhile, governments have already taken countermeasures and planned for the logistics system in devastated situations. But they do not have a clear image whether the planning transportation systems will or will not work, due to the fact that there is no tool to estimate that and nobody knows what happens after occurrence of disasters. The optimization techniques frequently reported these days do not directly give us the information on transportation performance reflecting damaged conditions. It is also unclear whether or not the actual transport operations can be conducted along with the optimized solution.

To estimate the performance of the transportation system under consideration quantitatively and qualitatively, the authors developed Support System for Transportation under Disaster Circumstance comprised of three tools. Figure 1 shows schematic of the system. GIS (Geographical Information System) is linking these tools as user interface in the system.

![Fig. 1 Schematic of support system for transportation under disaster circumstance.](image-url)

In this paper, one of the tools, a transportation simulator for relief goods, is focused. Features of the simulator and simulation examples are demonstrated.

2. Transportation Simulator for Relief Goods

Generally speaking, the role of the support system as countermeasures against disasters largely differs between using the system before and after a disaster. The simulator for the transportation of relief goods is envisaged to be utilized before a disaster. Users of the simulator are able to set various conditions reflecting disaster situation and are able to experience what happens after occurrence of disasters. The users may find some bottlenecks (cause of deterioration of transport performance) and are able to take precautions before the disaster. The essence to conduct transport operation (i.e. what should be determined) and corresponding elements are summarized in Fig. 2.

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The simulation process ends when all required relief goods are delivered or time given by user has passed. The simulator provides many useful outputs at the end of the simulation process. For instance, time history of the amount of the delivered cargo depicts the outline of the performance of the transportation system. Using the simulation result, user can judge the transportation system under consideration is appropriate or not.

2.3 Agent Rule

The agent rule is a process to determine next transportation job and it is executed afterward completion of a transportation job. The rule has two stages.

In the first stage, demand place (e.g. evacuation station or transfer point of relief goods) is determined. The simulator always updates the priority index of demand place requiring relief goods. The index for the priority is computed by the following equation.

\[ R_{ij} = A_{ij} / D_{ij} \]  \hspace{1cm} (1)

Where, \( R \) is priority index for ranking, \( D \) is required amount of relief goods, \( A \) is already shipped amount of relief goods, \( i \) is demand place (e.g. evacuation station) requiring relief goods, \( j \) is kind of relief goods (e.g. water, food, daily use products). Thus, the lower \( R \) means higher priority. Vehicle agents try to deploy the job for the demand place with the highest priority satisfying the following constraints.

- Compatibility of Cargo Type (i.e. \( j \) in Eq. (1)),
  (e.g. water and liquid fuel need tank)

- Compatibility of Transportation Mode
  (e.g. ship needs boatslip or proper facility)

This implies that relief goods are distributed evenly among demand places.

The second stage is determination of supply center. After a vehicle completes a transportation job (i.e. completion of unloading operation), the vehicle commences the process of agent rule, and at the same time becomes free vehicle (i.e. vehicle without job). If there are several candidates of the supply place, best place for the free vehicle is selected. The best place has the largest index, \( LT \), in the candidates and it is computed by the following equation.

\[ LT_{kj} = S_{kj} / T_{kj}, \]
\[ S_{kj} = \min(V_{kj}, C_{kj}) \]  \hspace{1cm} (2)

Where, \( V \) is cargo capacity of vehicle, \( C \) is storage amount of relief goods, \( k \) is supply place (e.g. warehouse, transportation center), \( j \) is kind of relief goods (e.g. water, food, daily use products). \( T \) is time to complete transportation job composed of following four processes.

- Moving to supply place (and waiting if number of vehicles at the place is in excess of the capacity of parking space)

- Loading Cargoes at Supply Center

- Moving to Demand Place (and waiting if number of vehicles at the place is in excess of the capacity of parking space)
2.4 α Vehicle Set

In some cases, however, transportation system becomes inefficient due to the independent execution of the agent rule. Figure 3 shows one example. In the figure, vehicle unloading cargo at demand place 2 is able to transport to demand place 3 via warehouse faster than the free vehicle that has just finished a job at demand place 3.

![Diagram of vehicle set](image)

Fig. 3 Example of ineffective case.

To avoid the inefficiency, the following process is considered. When a free vehicle appears and decides a demand place in the process of the 1st stage of the agent rule, the simulator makes a set of candidate vehicle. The candidate vehicle set is composed of free vehicle and vehicles unloading cargo at that time (hereinafter, α vehicle set). The free vehicle and the vehicles in α set compete the transportation job with the index computed by Eq. (2). The vehicle with the largest LT deploys the job and updates the priority index in Eq. (1). Above process in the second stage is summarized in Fig. 4 as flow diagram.

Computing vehicle allocation optimized completely is impossible due to the combinatorial explosion and the developed system is not optimization tool but simulator to observe what will happen. Thus the α vehicle set is limited to the vehicles unloading cargo.

3. Simulation

In this section, the application of the simulator with Multi-Agent System described previous section is demonstrated.

3.1 Simulation Condition

In Japan, the hierarchy structure like Fig. 5 is envisaged to transport under disaster circumstance if large area is damaged. It means that Japanese government is in charge for inter-prefecture transportation and prefecture is in charge for transportation from transfer point of prefecture to city, and finally, city is in charge of transportation between transfer point and evacuation center.

The simulator can reflect the hierarchy by executing simulations consecutively. In this paper, three simulations are combined. The first simulation described as “Simulation 1” in Fig. 5 is for the transportation from national logistics center to transfer points of Saitama, Chiba, Tokyo and Kanagawa prefecture by Japanese government. In the “Simulation 1”, amount of the cargoes delivered to the transfer points of the prefectures is accumulated as time history. In case of “Simulation 2” in Fig. 5, the supply capacity of the transfer point of the prefectures is limited by delivered amount in the “Simulation 1”. In case of “Simulation 3” in Fig. 5, it repeats above process in the same fashion. The Simulation condition for three cases is summarized in Table 1. The condition basically reflects disaster prevention plans of Japanese government, prefectures and cities [6].

Figure 6 shows street, sea lane and river network utilized for the simulation. The street network in this figure is priority emergency routes designated by the prefectures. The circles scattering in the network indicate transfer point of the prefectures and logistics center of the government locating at Higashi-Ogishima. Since the logistics center is only one, all relief
Table 1 Simulation condition.

<table>
<thead>
<tr>
<th>Item</th>
<th>By Government (Simulation 1)</th>
<th>By Prefecture (Simulation 2)</th>
<th>By City (Simulation 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Origin</strong></td>
<td>National Logistics Center</td>
<td>Transfer Point of Pref.</td>
<td>Transfer Point of Cities</td>
</tr>
<tr>
<td>(Parking Space)</td>
<td>(Truck:50, Ship:10)</td>
<td>(10 or 20; Depending on Place)</td>
<td>(10 or 20; Depending on Place)</td>
</tr>
<tr>
<td><strong>Destination</strong></td>
<td>Transfer Point of Pref.</td>
<td>Transfer Point of Cities</td>
<td>Evacuation Centers</td>
</tr>
<tr>
<td>(Parking Space)</td>
<td>(Truck:10 or 20, Ship:1)</td>
<td>(10)</td>
<td>(10)</td>
</tr>
<tr>
<td><strong>Vehicle</strong></td>
<td>400 Trucks (8ton Class) Capa. 4.8ton 50 Ships (Barge) Capa. 3ton</td>
<td>100 Trucks (4ton Class) Capa. 2.4ton</td>
<td>Trucks (2ton Class) Capa. 1.2ton Cities in Tokyo 20 Trucks The other cities 100 Trucks</td>
</tr>
<tr>
<td><strong>Moving Speed</strong></td>
<td>Truck: 15(km/hr) , Ships: 8(Knot)≈15(km/hr)</td>
<td>Cargo Handling Speed</td>
<td>Netword(Fig. 6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Truck , Ship : 100(kg/min)</td>
<td>Street, Sea Lane and River</td>
</tr>
</tbody>
</table>

goods are provided from the center. It is assumed that storage amount of the center is larger than the total demand amount (i.e. 12,900ton). The number, 12,900ton, is due to product of 4kg/person (Although the kind of relief goods is unspecified in this paper, water and food for one day or one blanket is about 4kg) and number of disaster victims who need relief goods. The number of disaster victims are estimated by a software provided from Japanese cabinet office [9], in which the condition is set to the earthquake in northern part of Tokyo bay (M7.3).

3.2 Simulation Result

In this section, simulation results under the condition set in the previous section are presented.

3.2.1 Transportation by Japanese government

Figure 7 shows time history of delivery amount by Japanese government from national logistics center at Higashi-Ohgishima to Saitama, Chiba, Tokyo and Kanagawa prefecture. It takes several hours that relief goods are delivered to the transfer points of the prefectures. After that, the delivery amount increases linearly and ratios of the delivery amount to the demand amount among four prefectures are nearly identical. It implies that the cargoes are distributed evenly by the priority index in Eq. (1).

Figure 8 shows a comparison of total delivery amount with and without α vehicle set described in section 2.4. The process making α vehicle set seems to be contrary to the principle of the Multi-Agent System based on autonomous-decentralized system. Because making α set requires a centralized agent collecting status information of all vehicles. In the figure, the delivery amount is the total delivery amount to the four prefectures in Fig. 7. The total delivery amount is almost same level between with and without the α vehicle set. This result implies that the condition, in which vehicle agents decide their transportation job independently without centralized control, doesn’t deteriorate transportation performance.

Figure 9 shows comparison between demand amount and total delivery amount of relief goods after 24 hours transport operation from national logistics center at Higashi-Ohgishima to transfer points of the prefectures. Figure 9 shows not only delivery amount by 400 trucks but also that of 800 trucks. About half of the demand amount of relief goods are delivered to the prefectures. But difference between 400 and 800 trucks is small.

Figure 10 shows why delivery amount by 800 trucks doesn’t increase. In case of 800 trucks, more than 300 trucks are waiting for the loading operation constantly, because the national logistics center is the only supply center, vehicles that complete their transportation job return to the center to load another
Figure 8 shows comparison of delivery amount with and without α vehicle set.

Figure 9 shows comparison of delivery amount after 24 hours and demand amount.

Furthermore, the parking space of the national logistics center is limited to 50 (Table 1). Thus, the shipping capacity is the bottleneck of the transport system. Figure 10 also shows that the shipping capacity is improved if the parking space can be extended to 100 and the delivery amount is also improved as is shown in Fig. 9.

Figure 11 shows comparison of delivery amount between ships and trucks. The delivery amount of ships is smaller than that of trucks. However, in case of Chiba prefecture it becomes around 20% of demand amount. Because location of Chiba prefecture is at the opposite shore of the national logistics center and ships can go straight, whereas trucks are made to detour along the shore.

3.2.2 Effect of road damage

Although delivery amount of ships is smaller than that of trucks, collapse of the street network by earthquake is significantly concerned. In such case, ships becomes alternative transportation mode. Although there are many factors to damage street network, such as collapse of buildings, fire and so on, liquefaction is considered in this paper. Because it actually arose and damaged street network in some areas of Tokyo by the Great East Japan Earthquake on March 11th 2011. Thick lines in Fig. 12 show streets on land where liquefaction is concerned. To investigate the effect of the damaged street, truck moving speed on the damaged street is reduced from 15(km/hr) to 3(km/hr), whereas ships hold 8(knot) (≈ 15(km/hr)). In the real world, development of sharing information system in disaster is advancing. In fact, some websites opened the information of road condition around the damaged area by the Great East Japan Earthquake.

Figure 11 shows simulation result as delivery amount of ships and trucks in the condition of damaged street. The delivery amount of trucks drastically decreases. Although the total delivery amount by ships is almost same level, its ratio against that of trucks increases and it implies that ship has potential to be alternative transportation mode in the case of street destruction.

Figure 8 shows delivery amount in the damaged street without α vehicle set too. However the difference is too small to see.

3.2.3 Transportation in Tokyo

This section demonstrates the transport operation in Tokyo Metropolitan. The delivered goods by government in “Simulation 1” of Fig. 5 is utilized in “Simulation 2” as supply goods to transfer point of cities in Tokyo. In the same manner, cities conduct transportation to evacuation center in “Simulation 3”. Figure 13 shows time history of delivery amount. In this figure, delivery amount of the government, Tokyo prefecture and cities are all overlapped. Naturally, delivery time for the cities is later...
than that for prefecture and delivery time for evacuation center is later than that for cities. However, the time lag between government and prefecture to reach same delivery amount increases, whereas the delivery amount by cities follows that of the prefecture. It implies that the transport performance of the Tokyo is slightly inferior to that of government and the condition of cities set in Table 1 is sufficient capability.

Fig. 13  Time history of delivery amount by japanese government, Tokyo prefecture and cities in Tokyo.

4. Conclusion

The authors developed “Support System for Transportation under Disaster Circumstance”. The system is comprised of three tools (Simulator of Relief Goods, Real time Transportation Support Tool and Analysis Tool for Stranded Commuters) and the Simulator of Transportation of relief goods is focused in this paper. Features of the simulator are demonstrated and simulation results show that it has capability to clarify bottlenecks of transport system. Since the simulator deals with various kinds of parameters regarding transportation systems, such as cargo handling speeds, characteristics of vehicles, networks, transportation centers and so on, small portion of its capability is introduced in this paper.

The simulation result without $\alpha$ set in Fig. 8 give us another possibility of the way conducting transportation in disasters. In that case, vehicles decide their action autonomously (where to deliver or where to pick up) without order and delivery amount is almost same to that with $\alpha$ set. It implies that a proper operation can be realized without government that will be in confusion in case of disaster, if a little information on shipping and demand amount is available for the drivers on vehicles. Thus, it is worthwhile to develop a system for sharing information.

Hoping that the simulator is widely used by administrative officers, engineers and researchers in contributing to the logistics in disasters, the authors have plan to open the simulation platform on the web in the future.

References

[9] Japanese cabinet office Web Site, http://www.bousai.go.jp/jishin/chubou/taisaku_chukin/shientool/index.html. However, the target area is different from this paper.

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