An Application of a Distribution-Supply Delivery Model to Relieve 9.0 Magnitude Tohoku's Earthquakes in 2011, Japan: A Case Study in Miyagi Prefecture

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The one thing that is a considerable emphasis in post-disaster is immediately delivery of relief items to victims. The model is presented to investigate the transportation cost and set up depot cost at the peak demand of relief items during the post-disaster. An improved supply distribution cost can reduce the expenditure of the whole of operation cost during the amelioration period. The 9.0 Magnitude Tohoku's Earthquakes in 2011, Japan is selected to study. An area of this study is focused in Miyagi prefecture, which is the most affected area and number of evacuees. Food, water and blankets are considered to be a requisite item for preliminary succor, which is separated in five difference cases of two scenarios analysis. These five scenarios were one-hierarchy analysis of depots and two-hierarchy analysis of depots with distinction by truck size. This model is solved by Genetic algorithm method, which offered the delivery cost and appropriate depot locations.

Key Words: *Distribution-Supply delivery, delivery cost, depots locations, earthquake*

1. INTRODUCTION

There are two types of disasters which are natural disaster and man-made disaster. Moreover, these types of disaster are also separated in two levels which are sudden-onset and slow-onset (L.N. Van Wassenhove, 2006). The classification of disasters is showed in the Figure 1. Recently, the natural disaster such as flooding, storm, fire, earthquake and tsunami is often occurs in the world, for the examples are the biggest blackout in North America in 2003, The Indonesian tsunami (and earthquake) in 2004, The Hurricane Katrina in 2005, The Heiti earthquake in 2010 and the Chilean one in 2010. There are many enormous effects in humanitarian which are including deaths, injuries, healthy, homeless, malnutrition and etc. In general, there are three steps in term of logistics which are Pre-disaster humanitarian logistics, During-disaster humanitarian logistics and Post-disaster humanitarian logistics. The Pre-disaster humanitarian logistics are including mitigation and preparedness. Next, the During-disaster humanitarian logistics are concentrated with the response. Other, the Post-disaster humanitarian logistics are consisted of response and recovery.

Thomas and Mizushima (2005) defined the humanitarian logistics that "It is the process of planning, implementing and controlling the efficient, cost-effective flow of and storage of goods and materials as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirments." *Van Wassen hove (2006)* proposed that "the humanitarians logistics consists of the processes and systems involved in mobilizing people, resources, skills and knowledge to help vulnerable people affected by disaster."

	Natural	Man-made
Sudden-onset	Earthquake Hurricane Tornadoes	Terrorist Attack Coup d'Etat Chemical leak
Slow-onset	Famine Drought Poverty	Political Crisis Refugee Crisis

Fig.1 The classification of disaster

On March 11, 2011, the 9.0 Magnitude Earthquakes and more than six meters of tsunami attacked in the northeastern of Japan. Then, it was followed by the 7.4 Magnitude aftershocks and 10 meters of tsunami occurred. This was the most severe seismic disaster in 140 years recording in Japan and was the one of five large scales in the world. There were a big number of people around 80,000 fatalities, 30,000 missing and 30,000 injured. Moreover, over than 50 million were homeless people because of effects from disaster such as flooding, building collapse, rock avalanches and mud flows etc. There were three main prefectures that were attracted by highest levels of tsunami which was approximately 10 meters. These prefectures were Miyagi, Iwate and Fukushima. Not only these prefectures but also more than 20 cities in Japan were affected by this disaster. Aftermath the tsunami was occurrence, the responsibility was a most importance to amelioration. The operations were separated in three levels which are a donor from international level, a prefecture level and a local city level.

During the post-earthquake, the delivery relief items are given priority. A major criteria for evaluating the efficiency of transportation is time and cost. These criteria relate with the operating such as the appropriate locations of depots.

Nagurney *et al. (2012)* presented that "disaster relief and associated cost are approximately 80 percent logistics. Therefore, more transparent, efficient, and effective logistics operations and supply chain management in disaster cannot save only lives but also enables better preparedness for natural as well as man-made disaster." These support that the logistics operation improvements are interested in the present.

Lin *et al. (2012)* focused on logistics efficiency improvement. They said that the prioritized items for delivery and an extensive time period are importance of humanitarian logistics. They would like to present the location of temporary depots around the disaster-effected area between the long travel distances of demand points and the central depots. The two-phase heuristic approach was presented. The best solution from Phase I, which was located the temporary depots and allocate covered demand area was assigned in Phase II to achieve the best logistics performance.

Wisetjindawat *et al. (2012)* studied on the vehicle routing model for distribution of emergency goods to victims. The time for responding was considered to develop the relief supply operation model in Aichi prefecture's plans for the locations of hubs. This model was applied for prediction Tokai, Tonankai and the coupled earthquake for Aichi prefecture. This study is solved by vehicle routing problem which was restricted by the maximum load of truck and working time of drivers.

2. OBJECTIVES

The 9.0 Magnitude Tohoku's Earthquakes are considered to investigate for the distribution relief items. The Miyagi prefectures which are most affected, are selected. The objectives in this study are following:

1. To search the appropriate locations of depots to distribution the relief items in Miyagi prefectures.
2. To estimate the cost for relief delivery under the transportation cost, fixed cost of depots and transshipment cost.
3. To compare the transportation cost between two structures are one-hierarchy and two-hierarchy of the depots with distinction truck size which are separated for five cases.

3. DATA COLLECTION

(1) The Number of Evacuees

In this case study, the number of victims is collected from the Miyagi Prefectural Government. They have published the evacuation situation and circumstances of the Great East Japan Earthquake. The number of evacuees is used for estimation the amount of relief items. The locations and the number of shelters are also illustrated. Moreover, the information about the prefectures that who are a supporter of them are provided in the records. These data can be locating the location of supply and shelter nodes.

(2) The Demand Estimation

The demand estimations are under assumptions of the vital items and the number of victims. The necessary items for daily life are served, which are consisting of foods, water and blankets. The foods and water are served for three meals per day. For each meal comprise 2-rice ball, canned food and 2-bread in a one box and 3-bottle of water per day.

The 4-ton trucks are carried eight pallets per a trip of relief items. The weight of one pallet is 420, 480 and 64 kilograms of foods, water and blankets respectively.

(3) The Transportation Cost

The transportation cost is under the assumptions that are separated in four sections of travel cost, fixed cost, transshipment cost and construction, rental building, electricity and water supply cost. Firstly, the travel cost is estimated by the fuel consumption of a small truck (4-ton) and a large truck (10-ton) which is approximately 7.69 and 11.54 yen per kilometer respectively. This travel cost varies with the distance between origin–destination nodes. Moreover, the transportation cost is also concluded a driver salary, purchase truck cost and vehicle insurance cost. Secondly, the fixed cost includes construction cost, rental building cost, electricity cost and water supply cost. This value is estimated equal to 3,000 yen per m^2 for first 1000 m^2 and 1,000 yen per m^2 after first 1000 m^2 for keeping space of goods as refer from the demand. Finally, the transshipment cost is around 5,000 yen per ton per day for loading or unloading of goods. This cost is included salary, bonus, social insurance and pension saving. This value obtains from the firm's Logistic Behavior Survey (PWRI) (Hosoya *et al.* 2003).

Travel cost = 7.69(distance) + (salary driver + purchase truck cost + vehicle insurance cost)

*salary driver (small trucks) = 3,750 yen per hour = 30,000 yen per day

*salary driver (large trucks) = 5,625 yen per hour = 45,000 yen per day

*purchase truck cost (small trucks) = 1,375 yen per day

*purchase truck cost (large trucks) = 2,063 yen per day

*vehicle insurance cost (small trucks) = 688 yen per day

*vehicle insurance cost (large trucks) = 1,032 yen per day

Transshipment cost = 5,000 (weight of items)

* loading and unloading = 5,000 yen per ton

Construction, rental building, electricity and water supply cost

*First 1,000 m^2 of cost = 3,000 yen per m^2

*After 1,000 m^2 of cost = 1,000 yen per m^2

4. MATHEMATICS

The objective function of this problem is proposed to be the optimization of delivery cost by selecting the appropriate depot locations. The single-source capacitated facility location models, which is contained in The Logic of Logistics (Bramel J. and Simchi-Levi D., 1999), provide a sequence distribution-supply delivery to gain the minimum delivery cost under the constraints, which are at least a one nodes is assigned, the maximum of depot capacity, the maximum containing weight or volume of trucks and the working time of drivers.

Sets of variables and parameters

N : set of the supply nodes; N
C : set of the demand nodes; C
D : set of the depot nodes; D
n : the supply nodes; n ε N
c : the demand nodes; c ε C
d : the depot nodes; d ε D
A : the types of commodities; a ε A
g_c : the demand size
c_{cn} : the travel cost between c and n
f_d : the fixed cost
b_{cn} : the transshipment cost at c-nodes and n-nodes
q_n : the capacity on the amount of demand it can serve
w_{sm} : the maximum containing weight of trucks
w_{sl} : the total containing weight of trucks
v_{sm} : the maximum load capacity of trucks
v_{sl} : the total load volume of trucks
t_{sm} : the maximum total working time of drivers
t_{sl} : the total working time of drivers

Decision variables

$$Y_d = \begin{cases} 1, & if\ a\ demand\ node\ is\ located\ at\ d \\ 0, & otherwise, \end{cases}$$

for d ε D

$$X_{cd,slm} = \begin{cases} 1, & if\ a\ demand\ node\ c\ is\ assigned\ to\ a\ supply\ node\ d, by\ truck\ size\ s \\ 0, & otherwise, \end{cases}$$

for c ε C and d ε D

Objective functions

$$min\left\{\left[\sum_{s}\sum_{l}^{m}\sum_{c=1}^{C}\sum_{n=1}^{N} c_{cn} X_{cd,slm} + \sum_{d=1}^{D} f_d Y_d + \sum_{c=1}^{C}\sum_{n=1}^{N} b_{cn} Y_d\right]_a\right\}$$

Constraint functions

$$\sum_{d=1}^{D} X_{cd,slm} = 1 \qquad \forall c \in C$$

$$\sum_{c=1}^{C} g_c X_{cd,slm} \leq q_d Y_d \qquad \forall d \in D$$
$$w_{sl}(X) \leq w_{sm}$$
$$v_{sl}(X) \leq v_{sm}$$
$$t_{sl}(X) \leq t_{sm}$$
$$y_d \in \{0,1\}\ for\ all\ d$$
$$X_{cd,slm} \in \{0,1\}\ for\ all\ pair\ nodes\ c-d$$

5. DATA COLLECTION AND RESULTS

The relief items were received from eight regions over the countries; these are illustrated to be 29 nodes as call origin or supply nodes which are shown in the Table 1. The faraway prefectures are assumed to be a group as the center of a region which is including NIKKI, CHUGOKU, SHIKOKU and KYUSHU-OKINAWA. These supply node locations are based on the reported data situations in Miyagi Prefectural Government.

Likewise, there are 39 nodes to receiving the relief items in Miyagi prefecture as known as destination or shelter nodes which are illustrate in the Table 2. These locations are referred from the locations of shelters in Miyagi prefecture. Sendai has five shelters by the reason that there is the high density of victims.

The demand of the relief items is estimated by the number of evacuees in each shelter which is shown in the Figure 2. The number of victims is about nine percent of all population in Miyagi prefecture. There are three types of necessary items which are food, water and blankets. This number of victims is the peak amount during the first seven day of post-disaster. The 4-ton and 10-ton trucks are used for delivery these items. The 4-ton trucks can contain eight pallets of volume or four tons of weight and the 10-ton trucks can carry twice time of goods. The delivery is assumed that the types of items are separately carrying in the trucks. The number of trucks is assigned to unlimited availability. However, the working time of drivers is set to be not over than 8-hour per day. The shortest distance of route is determined for giving a lowest of transportation cost.

Table 1 The supply locations.

No.	Supply node	No.	Supply node	No.	Supply node	No.	Supply node
1	Hokkaido	9	Saitama	17	Toyama	25	Aichi
2	Akita	10	Chiba	18	Namerikawa	26	NIKKI (Kansai)
3	Yamagata	11	Tokyo	19	Ishikawa	27	CHUGOKU
4	Niigata	12	Ushiku	20	Kanazawa	28	SHIKOKU
5	Tochigi	13	Yokohama	21	Yamanashi	29	KYUSHU-OKINAWA
6	Gunma	14	Tokorozawa	22	Shizuoka		
7	Ibaraki	15	Itoigawa	23	Gifu		
8	Nogi-machi	16	Joetsu	24	Ogaki		

Table 2 The demand locations in Miyagi prefecture.

No.	Demand node	No.	Demand node	No.	Demand node
1	Aoba-ku Sendai	14	Tome	27	Matsushima-machi
2	Izumi-ku Sendai	15	Kurihara	28	Shichigahama town
3	Miyagino-ku Sendai	16	Higashimatsushima	29	Rifu town
4	Taihaku-ku Sendai	17	Osaki	30	Taiwa-cho
5	Wakabayashi-ku Sendai	18	Zao-machi	31	Osato town
6	Ishinomaki	19	Shichikashuku town	32	Tomiya
7	Shiogama	20	Ogawara-machi	33	Ohira village
8	Kesennuma	21	Murata town	34	Shikama town
9	Shiroishi	22	Shibata town	35	Kami-machi
10	Natori	23	Kawasaki	36	Wakuya town
11	Kakuda	24	Marumori town	37	Misato
12	Tagajo	25	Watari-cho	38	Onagawa-cho
13	Iwanuma	26	Yamamoto-cho	39	Minamisanriku-cho

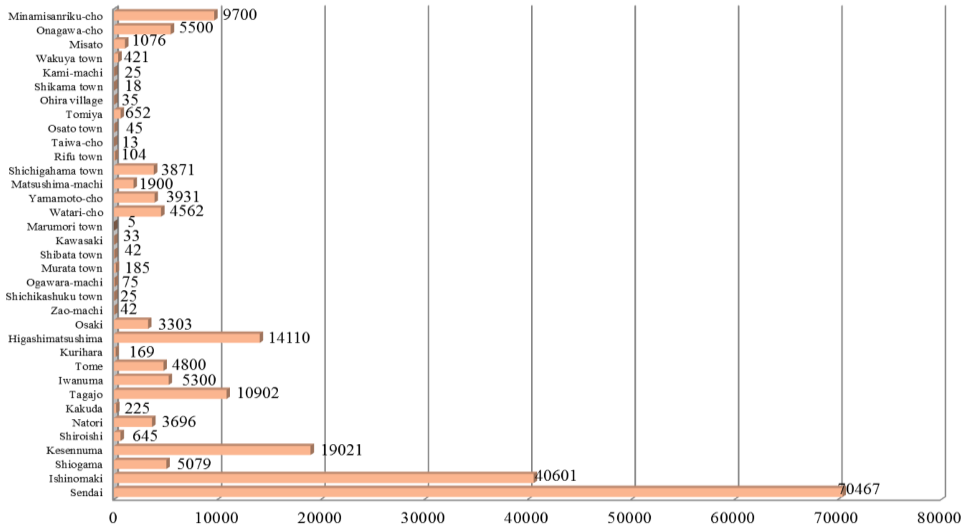


Fig.2 The number of evacuees in each shelter node.

(1) First Scenario

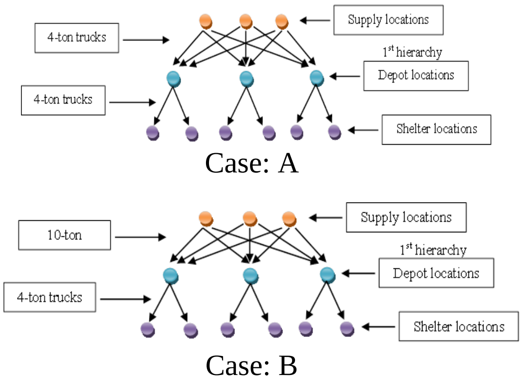


Fig.3 The structures of one-hierarchy analysis

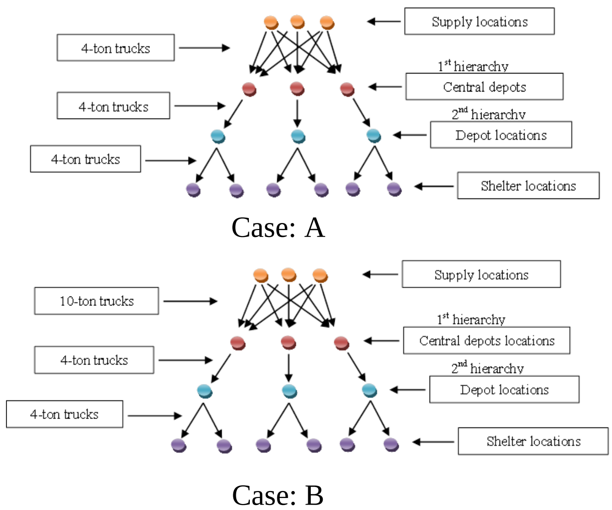
The first Scenario is designed the transportation cost by considering one-hierarchy analysis of depots for distribution. The relief items are sent from the supply location nodes to the depots then, it is distributed to shelter location. There are two conditions of truck size distinctions for a comparison which is 4-4-ton trucks and 10-4-ton truck as shown in the Figure 3.

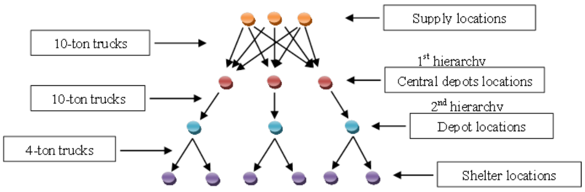
The Genetic Algorithm method is applied for the data analysis. It is determined that the sample size of population is included four chromosomes by randomness. Each chromosome is referred to the number of depot locating. The structures in the chromosome are assigned to be binary representation, which 0 is not located the depots at that site and 1 is located the depots at that site. This study is calculated at 10,000 times for the max generation creating. It is determined that they transfer by one-point crossover which has the crossover probability and mutation probability equal to 0.7 and 0.1respectively.

The results of 4-4-ton trucks are shown that there are 19 nodes from 39 nodes to be the depots for a supply delivery which are illustrated as followed: Aoba-ku Sendai, Izumi-ku Sendai, Miyagino-ku Sendai, Taihaku-ku Sendai, Wakabayashi-ku Sendai, Ishinomaki, Shiogama, Kesennuma, Natori, Tagajo, Higashimatsushima, Marumori town, Watari-cho, Yamamoto-cho,Matsushima-machi, Shichigahama town, Osato town, Kami-machi, Onagawa-cho. The calculation presents around 238 million yen per day for delivery cost of the whole step.

The 10-4-ton trucks models are received 14 nodes from 39 nodes to be the depots for the distribution of relief items, the locations are Aoba-ku Sendai, Izumi-ku Sendai, Miyagino-ku Sendai, Taihaku-ku Sendai, Wakabayashi-ku Sendai, Ishinomaki, Kesennuma, Shiroishi, Tome, Higashimatsushima, Osato town, Tomiya, Kami-machi, Onagawa-choshown. The transportation cost is approximately 185 million yen per day.

(2) Second Scenario





Case: C

Fig.4 The structure of two-hierarchy analysis

After the first scenario achievements, the second scenario is design for two-hierarchy of depots. The depot locations are not fixed to be a central depot for collection all of relief items. It will be selected by the reason that there are the appropriated locations with the minimum delivery cost. In this step, the 4-ton trucks and 10-ton trucks are assigned to carry the relief items to the central depot layers which are shown in the Figure 4. Subsequently, the relief items will be delivered to the depots. Finally, these relief items are sent by the small trucks (4-ton) to the shelters. There are three cases for distinctions of truck size which is 4-4-4-ton trucks, 10-4-4-ton trucks and 10-10-4-ton trucks.

The calculation of 4-4-4-ton trucks are illustrated that the delivery cost is approximately 349 million yen per day which is selected six nodes to be the central depots and 15 nodes to be the depots. The six of central depots are Miyagino-ku Sendai, Shiogama, Iwanuma, Murata town, Shichigahama town, Taiwa-cho and the 15 depots are Aoba-ku Sendai, Izumi-ku Sendai, Taihaku-ku Sendai, Wakabayashi-ku Sendai, Ishinomaki, Kesennuma, Shiroishi, Tagajo, Kurihara, Higashimatsushima, Osaki, Shichikashuku town, Ohira village, Onagawa-cho, Minamisanriku-cho .

The 10-4-4-ton trucks cases, the same structure of hierarchies is set but there is the distinction on truck size. The large trucks (10-ton) are assigned to carry the relief items from supply nodes to the central depots. The relief items to the central depots are delivered by a large truck which can carry the twice time of goods. The consumption rate for the large truck is multiplied by 1.5 time of small truck consumption rate. Subsequently, the relief items will be delivered to the depots by the small trucks (4-ton) same as before. This is presented the delivery cost approximately 262 million yen per day. There are five nodes to be the central depots which are Aoba-ku Sendai, Shiogama, Shibata town, Ohira village, Onagawa-cho and 12 nodes to be the depots which are Izumi-ku Sendai, Miyagino-ku Sendai, Taihaku-ku Sendai, Wakabayashi-ku Sendai, Ishinomaki, Kesennuma, Shiroishi, Tagajo, Iwanuma, Higashimatsushima, Osaki, Osato town, Minamisanriku-cho, Wakuya town.

The last case is 10-10-4-ton trucks which are applied for the large truck size to send the relief items from the supply nodes to the central depots. Not only these are applied but the large truck size is also used for delivery from the central depots to the depots. Finally, relief items are sent by the small trucks (4-ton) to the shelters. This is calculated the delivery cost about 203 yen per day with the eight nodes of central depots and 11 nodes of depots. Kesennuma, Natori, Tagajo, Tome, Osato town, Higashimatsushima, Yamamoto-cho, and Tomiya are the central depots. Izumi-ku Sendai, Miyagino-ku Sendai, Taihaku-ku Sendai, Wakabayashi-ku Sendai, Ishinomaki, Iwanuma, Shikama town, Misato, Onagawa-cho and Minamisanriku-cho are the depots.

6. COMPARISION

This section is evaluated the delivery cost between the real situation and the results from the study that there are differences of depot locations. The best cases from the study are compared. The structure of delivery is one-hierarchy. There are 15 nodes which are presented to be depots in the real situation. The 4-ton trucks are used to deliver both from supply nodes to depots and from depots to shelters. The total cost is 238, 943,502 million yen.

Table 3 The locations of depots from the real situation and results of the study.

Real situation		Study
1	Ishinomaki	Aoba-ku Sendai
2	Iwanuma	Izumi-ku Sendai
3	Ogawara-machi	Miyagino-ku Sendai
4	Kesennuma	Taihaku-ku Sendai
5	Shiogama	Wakabayashi-ku Sendai
6	Shichigahama town	Ishinomaki
7	Sendai	Kesennuma
8	Tagajo	Shiroishi
9	Tome	Tome
10	Natori	Higashimatsushima
11	Higashimatsushima	Osato town
12	Matsushima-machi	Tomiya
13	Minamisanriku-cho	Kami-machi
14	Yamamoto-cho	Onagawa-cho
15	Watari-cho	

6. CONCLUSION AND FUTURE RESERCH

The relief item distribution for 29 nodes of origin (supply) from the whole country of Japan and 39 nodes of destination (demand) in Miyagi prefecture are analyzed by Genetic Algorithm method. This study aims to minimize the delivery cost by searching the optimal locations of depots. There are five situation analyses to comparison the delivery cost. These situations are the one-hierarchy of depots and the two-hierarchy of depots with the truck size differences. The transportation cost comparison of these scenarios is shown in the chart of Figure 5.

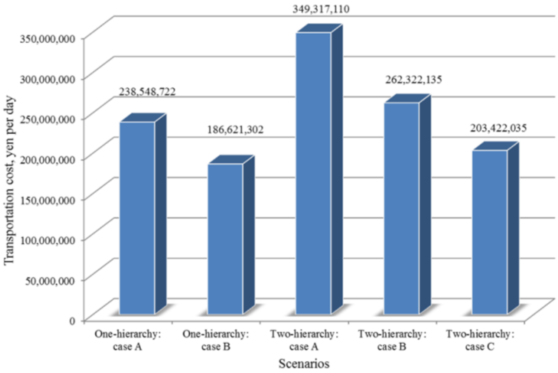


Fig.5 The delivery cost comparison of five scenarios.

The lowest result of the relief item delivery spends around 186 million yen per day which is the situation of one-hierarchy: case B scenarios. This cost offers lower around 46.58 percent of the highest delivery cost, two-hierarchy: case A.

From the model of case B in one-hierarchy analysis shows that there are 14 sites of proper depots which offer the lower transportation cost about 21.76 percent or around 52 million yen cheaper when compared with the case A of the same structure. Moreover, it is also received the transportation cost saving at 23 percent with no providing the depots. The result of this study is illustrated that the finding of appropriate depots can increase the efficiency of operation cost. The model can examine that the depot locating is an importance. However, the other factors are also must considerate such as set up cost of depots and loading/unloading cost etc.

After that, the second scenario is setting up the central depots by finding the minimum transportation cost. The case C of second scenario offers the transportation cost at around 203 million yen or 41.77 percent cheaper than the case A, which offers the highest delivery cost in same scenario. There is the transportation cost saving approximately 146 million yen per day. Therefore, this scenario is used for investigation. This scenario is not only concentrated on hierarchy of depots but also concerned on the distinction of truck size. This step proves that the large truck size can reduce the delivery cost under the lot sizes.

However, the comparison between two scenarios demonstrated that the one-hierarchy is given the lower transportation cost than two-hierarchy. The best cases of each scenario are one-hierarchy case B and two-hierarchy case C respectively. The comparisons are shown that the one-hierarchy case B is illustrated lower transportation cost than the two-hierarchy case C, which is approximately 17 million yen per day or 8.26 percent. These two scenarios are supported that the structure of hierarchy is an importance. It can show some benefits after this condition is applied.

The results from the model show that there are lower of the transportation cost than the real situations with the same structure, one hierarchy, Figure 6.

The comparison of the real situation with the one-hierarchy case A and the best case, the percentage difference is reduced 0.17 percent and 21.90 percent respectively. The one-hierarchy case A is a little cheaper than real situation. This scenario is the same structure and same truck size delivery but distinct depot locations. Therefore, this means that there are many depots locations can be proposed. Around 22 percent of transportation cost reducing is illustrated with the best case. The one different is truck size to deliver. Therefore, it can prove that the model results of 10-ton trucks are more transportation cost saving.

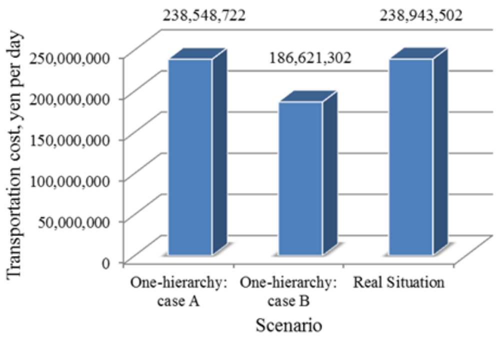


Fig.6 The delivery cost comparison with the real situation.

As refer to the introduction that the two apparent criteria in logistics are the aspect of cost and time. Therefore, the future study would like to present the multi-objective function. This plan is to set two objectives. The first objective is minimizing of a set up depot cost and the second is minimizing of time for delivery cost simultaneously. Caunhye *et al. (2012)* reviewed that there is a lack of multi-objective model in facility location models. They concluded that only Mete and Zabinski optimized the warehouse operation costs and the total transportation cost together.

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