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A NUMERICAL SIMULATION OF DISASTER WASTE DISPOSAL IN WAKAYAMA CITY BY USING DHT MODEL

Soichiro ASAI[1], Tatsuya AKIYAMA[2], Hiroto TANOUCHI[3], and Nobuyuki EGUSA[4]

[1]Graduate School of Systems Engineering, Wakayama University, Japan; [2,3,4] Faculty of Systems Engineering, Wakayama University, Japan

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ABSTRACT: We conducted a numerical simulation of disaster waste disposal by using a Dynamic Hauling/Transportation model (DHT model) in order to extract the factors to hinder the execution of a disposal management plan of Wakayama city government. The DHT model was developed for estimating number of days required for disaster waste disposal, following parameters are mandisopdatory as the model inputs; (1) disaster waste characteristics (distributions, volume and contents) in damaged area, (2) hauling/transportation route, (3) number/capacities of transportation vehicles, (4) maximum capacities at temporary storage / final disposal sites and (5) abilities of crushing/classification equipment. Almost all parameters were set by referring to a planning document of disaster waste disposal provided by Wakayama city and disposal guidelines published by Ministry of the Environment of Japan. Several parameters without description in these document/guideline, e.g. maximum capacities at temporary storage and distance of hauling/transportation route were estimated by using GIS. Severe shock and tsunami caused by Nankai Trough huge earthquake were adopted as external forces generating disaster waste. By assumption that parameters included in (3) and (5) could be critical parameters for a result of simulation, we performed sensitivity analysis of each parameter in them. As a result, abilities of several crushing / classification at temporary storages were the most sensitive parameters of all evaluated parameters. Therefore, augments of crushing/classification functions at temporary storage might be effective to shorten processing days for disaster waste disposal.

Keywords: Disaster waste disposal, Dynamic hauling/transportation model, Sensitivity analysis, Nankai Trough huge earthquake, Wakayama city

1. INTRODUCTION

An appropriate planning of disaster waste disposal is a great issue in a disaster recovery phase. Although it is therefore necessary to make appropriate assumptions about disasters and develop an ideal disposal management plan, it is generally difficult to formulate it with flexibility based on regional characteristics. This is particularly problematic other than large cities with vast population because of a lack of specialists and little financial leeway[1]. Wakayama city is also expected a huge amount of disaster waste generation caused by a Nankai Trough huge earthquake, a numerical system to support a waste disposal planning is effective in this regard.

Various investigations and studies have been conducted in order to establish efficient disaster waste treatment plans. Tanikawa et.al. [2] developed an accurate prediction method of the amount of disaster waste generation by considering material stocks of buildings and roads. Nasu et.al. [3] implied governments of several cities had been adopted inadequate assumption methods to estimate amounts of disaster wastegeneration. For instance, disaster waste amount caused by Tsunami shown in some waste disposal plans were calculated by using other disaster, e.g. strong earthquake without Tsunami. On the other hand, few researchers have addressed to develop numerical simulation models for disaster waste disposal management. Kayo et. al. 2011 proposed a simplified model to estimate financial/temporal cost for disaster waste disposal in Miyagi prefecture[4]. Sakaguchi et. al. 2018 developed a DHT model, which is a prototype of the numerical system to model all transport/hauling processes in the disposal plan. They also applied it for an actual city[5].

There remains a need for a lot of application of the numerical simulation such as the DHT model to evaluate actual disaster waste disposal plans published by a lot of governments. The amount and quality of disaster waste have great varieties depending on a target city, various patterns of transport/hauling processes also exist. Therefore, a model specialized and optimized for each target city is demanded in order to increase the number of applications. In this study, we have applied the DHT model targeting on Wakayama city as a new case study. In addition, we discussed to formulate a more appropriate planning than one proposed in this

Table 1 Input parameters of DHT model. Parameter is classified 1) type of set up by referring to official documents by governments, 2) type of set up by referring to environments of the Great East Japan Earthquake, 3) type obtained by GIS processes, 4) assumed value in this study originally. Subscripts shows i;SID , j: type of disaster waste(number of waste types were 6 in this study), k:toSID, l:link ID (number of links were 249 in this study), m: type of trailers (only 1 in this study)

kind	variable	Description	unit	value	type
Storages	SID	Storage ID	-	1 to 72	
	Vol_i	Facility storage volume	ton		3)
	$Su_{i,j}$, $Sa_{i,j}$	Amount of disaster waste (untreated /treated)	ton		3)
	$C\_R_{i,j,k}$	Proportion of the volume transported to multiple destination sites.	-		4)
Links	$frSID_l$, $toSID_l$	Import SID Export SID	-		3)
	$Dist_l$	Route length	km		3)
	Spd_l	Average speed	km /hour	30km/hour	4)
	$Load_l$	Loading time,	hour	30 minutes	1)
	$Unld_l$	Unloading time		20 minutes	1)
Transports	$TPNum_m$	Number of trailers	-	1245	4)
	$TPAbility_m$	Capacity of trailers	ton	10	1)
Classify	$CLNum_s$	Number of crushing / classification machines	-		2)
	$CLAbility_s$	Ability of crushing / classification machines	ton/hour		2)

study through an evaluation about bottlenecks of disposal planning of Wakayama city.

2. METHOD

2.1 Figures

The DHT model is a kind of process-based, mass transfer and state change model, optimized for reproduction of disaster waste disposal. In actual disposal management, waste spread in damaged area generated by a catastrophic forcing are transported and hauled to each disposal facilities and storages step by step, aiming to disappear the waste from the area. In the model, all processes of them can be reproduced.

Figure 1 shows the general flow of disaster waste disposal. Reproduced processes in the model are followings; (1) Disaster waste generated in damaged area is transported to refuse collection places. In this phase, disaster waste is generally unsorted and many types of material are mixtures in it. (2) Then, this mixed der waste is transported from the collection places to primary temporary storages. (3) At the primary temporary storage, the disaster waste is separated based on material types. Here, crushing process is also installed generally in order to facilitate transportation, recycling and disposal. (4) Residual mixed waste generated by insufficient separate capability at the primary storages is transported to secondary temporary storages. (5) These transported residual mixed waste undergoes more advanced separation and crushing processes than the primary storages in the secondaries. (6) Disaster waste sufficiently separated and crushed in the primaries and secondaries are transported to disposal sites or recycling facilities based on the type of waste. (7) In these sites and facilities, disaster waste is completely disposed or recycled (e.g. landfill, recycling facility, incinerator). Concrete procedures of calculation in the model is shown in [5].

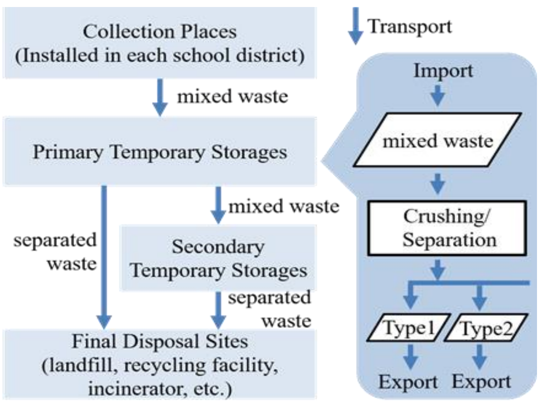

Fig. 1 General disaster waste management flow.

2.2 Parameters

Table 1 shows mandatory parameters in the DHT model. Although temporal flexibility of each parameter was necessary in order to reflect process changes accompany with disposal plan progression, each parameter value was fixed as initial values during the simulation in this study. Additional function to adjust parameters even in a progression of analysis is necessary in future.

In this study, 1) the parameters were set basically by referring to official documents showing disaster waste planning published by Wakayama prefecture[6], Wakayama city[7] and Ministry of the Environment, Japan[8]. 2) Several other parameters without shown in these documents were set based on environmental value obtained by the Great East Japan Earthquake[9]. 3) In other parameters, especially location and capacity of each storage were estimated by GIS processes. 4) The other parameters impossible to obtain related information were set as reasonable values in our assumption.

2.3 Input and output

The input is spatial distributed disaster waste data, an arbitrary number of types and volume of disaster waste can be set in the model. Although a geospatial size of each input unit is also arbitrary, elementary school districts are often appropriate for the units because they have been adopted as the units for actual disaster waste disposal in previous managements. The output of the model is amount of each disaster waste type stored in each facility at each time step and required date to complete disaster waste disposal.

3. PROPERTIES OF TARGET AREA AND MODEL SET-UP

3.1 Study area and target disaster

Figure 2 shows the location and properties of a target area of this study. The target area was Wakayama city, Wakayama prefecture, Japan. Wakayama city is located in coastal area facing the Pacific Ocean, which has about 350 thousand of population and about 150 thousand of households. The city consists of 48 elementary school districts, total area size of it is 209 km^2. Especially industrial areas extend along the coast in the city.

A targeting disaster in this study was Nankai Trough huge earthquake, we took especially disaster waste generated by strong earthquakes and Tsunami into account. Wakayama city government inscribed in the report[9] that a vast area facing the Pacific ocean would be swallowed by the Tsunami, and most areas would receive a severe earthquake with a seismic intensity of 6 at least.

3.2 Transport and disposal network

Figure 2 also shows locations of collection places, primary and secondary temporary storages, disposal site and recycling facilities. Collection places were set as schoolyards of elementary schools, disaster waste generated in each district is firstly transported here. Information related with final disposal sites for combustible waste and incombustible waste were also mentioned in official documents[6],[7]. locations and capacities of disposal system of them were set by referring them. On the other hand, no detailed description related with recycling facilities were however shown in them. We therefore established recycling facilities for 4 materials (wood, concrete, metals and tsunami sediments) uniquely.

The guidelines of the Ministry of the Environment[7] noted a policy to set temporary storages. While referring to it, Candidates of primary or secondary temporary storages were raised by extracting open spaces (e.g. parks, parking lots and grounds) by GIS processes. Criterion to extract both types of storages were 1) exceeding 10,000 m^2 area size, 2) not located in riverside land to avoid secondary disaster caused by flooding, 3) not adjoined disaster base hospital. By these criterions, we obtained 13 sites as candidates of temporary storages. Then, the largest site of them were set as secondary temporary storages because

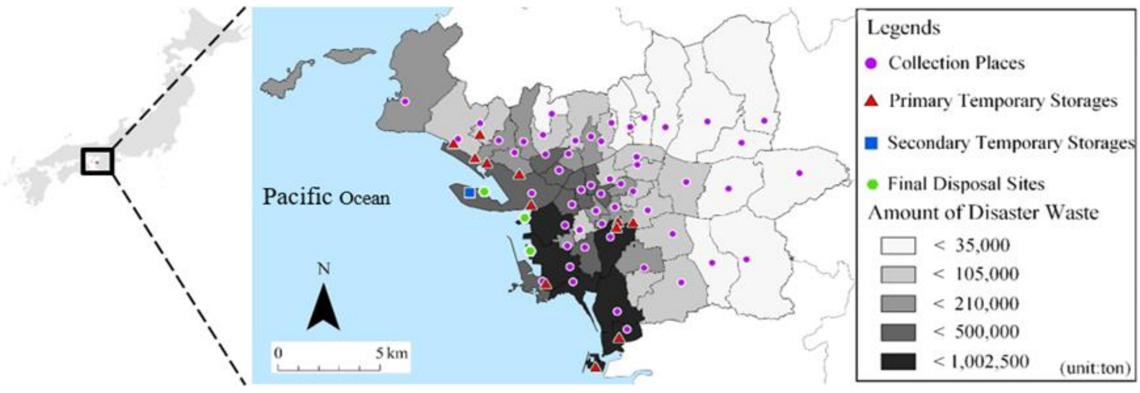

Fig. 2 The location of all sites and the amount of disaster waste in each school district.

of small distances between it and final disposal sites and recycling facilities. Finally, all candidate sites except chosen as secondary temporary storage were set as the primary storages.

As a result, there were 53 collection places, 12 primary temporary storages, 1 secondary temporary storage and 6 final sites (including final disposal sites and recycling facilities). Figure 3 shows the connection relationship of all sites. All collection places were connected to three primary temporary storages chosen in close order. Here, all distance between the collection places and primary temporary storages were calculated as them along roads. All primary temporary storages were connected to the secondary temporary storage. Secondary temporary storage was also connected to all final disposal sites. All connections were one-way from upstream to downstream. Transportation vehicles allocated links of completed disaster waste exporting were re-allocated for other links. A rule of the re-allocation is to priory for links of upstream, e.g. links from collection places.

Aiming at mitigation the burden on the damaged areas, an exportation from damaged municipalities to outside area is generally performed. In this study, however this kind of outside processing was not modeled because of facilitating interpretation of the results. This obvious limitation in this study could lead to results that the period required for waste disposal is calculated unfairly longer than actual.

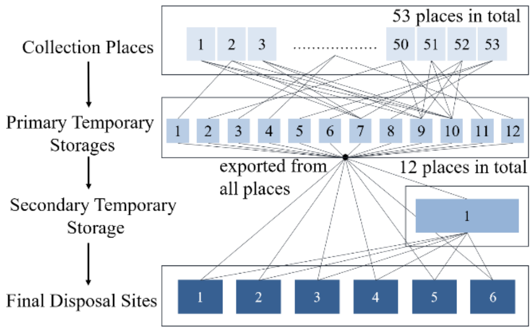

Fig. 3 Network structure in Wakayama city.

3.3 Capacity of each storage[7]

The capacity of each primary or secondary temporary storages was set as follows:

$$Cap = Area \times ASG \times SH \,/\, (1 + WSR) \qquad (1)$$

Where, Cap is weight based capacity of each storage (t), $Area$ is area size (m^2). ASG is an apparent specific gravity (t/m^3), shown in table 2, respectively. SH is stacked height (m), the value was set on 5m as an empirical value. WSR is an indicator related to a vacant space without stacking with disaster waste to improve work efficiency, the value was also empirically set as 1.

Table 2 The value of the ASG

No	Type of waste	ASG (t/m^3)
1	Wood	0.55
2	Concrete	1.48
3	Metal	1.13
4	Tsunami Sediments	1.46
5	Combustible	0.4
6	Incombustible	1.1

3.4 Spatial-distributed input data creation

By allocating various types of waste generated both tsunami and earthquake forcing to each elementary school district, we created the spatial distributed data set of disaster waste as model input. Methods to estimate the amount of disaster waste was obtained by the Wakayama Prefecture's disposal management plan[6]. In this study, disaster waste was classified waste debris or tsunami sediment, both of them were calculated for each school district. The following assumptions were applied to calculate the amount of disaster waste. 1) Debris was generated only from buildings for housing, we ignored debris origin from road or other structures. 2) All buildings are wooden. 3) Despite of existence of various levels of destruction, only completely destroyed buildings are taken into the estimation. 4) Ages of buildings required to estimate durability of them were obtained by Japanese statistical survey 2018[10]. Eq. (2) show equations to calculate the amount of debris[5].

$$Q = s \times N \times q \qquad (2)$$

Where Q is total amount of debris in each waste type(t), s is average gross floor area of building (m^2). N is number of buildings destroyed. q is debris generation per unit area of floor. In [6], q was although describes as different values based on debris types as respective (e.g. 0.194 (t/m^2) in combustibles), we used $q = 0.696$ (t/m^2) as total value of all debris types in order to estimate Q as the sum of all types. On the other hand, s and N were not shown in each disposal management plan, we replaced $s \times N$ with $TFA \times CDR$ as follows:

$$Q = TFA \times CDR \times q \qquad (3)$$

Where, TFA is total floor area of each school district, CDR is completely destroyed rate by tsunami or earthquake forcing. In areas with duplicated attacks both tsunami and earthquake forcing, CDR come a value as the sum of tsunami's CDR and earthquake forcing's CDR. If the total CDR exceeded 100% by this calculation, it was modified 100%. More detailed theory and procedures to estimate disaster waste amount by using CDR were described in some documents published by governments (e.g. [11]).

Finally, total debris amount of each school district was classified based on debris types. Some documents related with past disaster waste managements have indicated contents and volume of disaster waste, we adopted a ratio of constituent substances in debris obtained by a waste management of the Great East Japan Earthquake[5]. Table 3 shows the ratio of constituent substances and the amount of disaster waste generated by type in the entire Wakayama city. Total weight of Q exceeds 10 million ton, which is equivalent to total waste generation for 70 years in Wakayama city under non-disaster condition[7].

Table 3 Amount of the disaster waste

No	Type of waste	Ratio (%)	Amount (million ton)
1	Wood	4.5	0.563
2	Concrete	43.2	5.418
3	Metal	5.5	0.688
4	Tsunami Sediments	17.0	2.133
5	Combustible	14.9	1.876
6	Incombustible	14.9	1.876
	Total	100.0	12.554

The amount of tsunami sediment was calculated as follows:

$$Sd = A_{tus} \times d \times k \qquad (4)$$

Where Sd weight of tsunami sediment in each school district(t), A_{tus} is area size of inundation (m^2), d is average depth of inundation(m). k is conversion factor from inundation depth to deposition amount per unit area by empirical rule[6]. Finally, Total weight of Sd exceeds 2 million ton.

An estimated amount of disaster waste (sum of Q and Sd) at each school district was also shown in figure 2. Larger proportion of disaster waste was generated in the coastal area, the impact of the tsunami was strongly shown.

4. RESULTS

Figure 4 represents the time series of the disaster waste amounts in each phase estimated by an analysis under the above condition. A period to disappear disaster waste from all collection places was 22.7 years, which is the same as a period from disaster forcing to export disaster waste from all primary temporary storages. Finally, it was demanded 22.8 years to complete disposal process for all disaster waste.

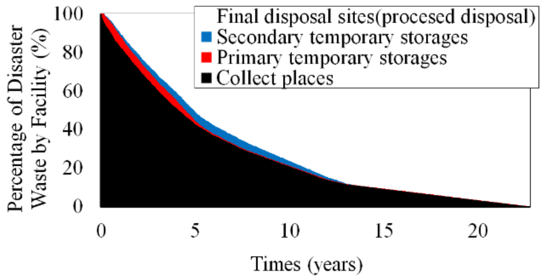

Fig.4 A time series of the disaster waste amounts of collection places, primary and secondary temporary storage, processed in final disposal sites in total.

Periods required under ideal conditions without bottlenecks in transportation or separation could be simply estimated by dividing of each types of disaster waste amount by ability of disposal site for each type, the longest of them was calculated as 8.4 years. This period is much smaller than the period obtained by the numerical simulation in this study.

Figure 5 shows utilization rate of primary and secondary temporary storages, it was shown that especially secondary temporary storages were mostly vacant trough the disposal period. In addition, primary temporary storages were also un-used efficiently especially mid to late in disposal. These results suggested that enhancement and optimization for transportation and separation were critical issues for efficient disaster waste disposal planning. On the other hand, it was also shown that fundamentally enhancements of function final disposal sites were also necessary for further shorten of date to complete all disposal process.

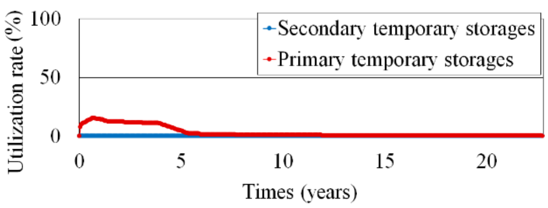

Fig.5 Utilization rate of primary and secondary temporary storages in whole disposal period.

5. CONCLUTION

In this study, the DHT model was applied to Wakayama city to simulate a disposal process of disaster waste caused by the Nankai Trough Earthquake. Although the process of collection/transportation was modelled based on reasonable ideas, temporal storages were not utilized well chronically. In this case, this surplus caused inefficiency of the entire processes and a delay the processing period. This result suggested that enhancement and optimization for transportation and separation were critical issues for efficient disaster waste disposal planning in Wakayama city. One of the notable limitation of this study is not to reflect outsourcing outside the disaster area. The outsourcing might be effective for further shortening the processing time if these kind of enhancement and optimization had been well-performed. Development of methods for enhancement and optimization are considerable issue in order to improve convenience of the DHT model, we plan to work on this in the future.

6. ACKNOWLEGEMENTS

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7. REFERENCES

[1] Ministry of the Environment, Discussion of the status and promotion of disaster waste management plan development, 2020, https://www.env.go.jp/recycle/waste/disaster/earthquake/committee2/r1-02/R1_2_02_-keikakusakutei.pdf, Accessed 2020/6/23

[2] Hiroki T., Shunsuke M. and Cherry M.L., Estimates of Lost Material Stock of Buildings and Roads Due to the Great East Japan Earthquake and Tsunami, Journal of Industrial Ecology, Vol.18, Issue 3, 2014, pp.421-431.

[3] Yuta N., Akifumi N., Syuiti Y., Yugo Y., Mineo T. and Noboru Y., Analysis on Intensity of Waste Generation in Prefectural Disaster Waste Disposal Plans and Influence in Existing Plan in Wakayama Prefecture, Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research), 2019 Volume 75 Issue 6 Pages II_261-II_271.

[4] Chihiro K., Koichi T., Tomonori I., Kazuto E. and Masato Y., Development of Support Tool for Seismic Disaster Waste Treatment Planning - Waste Distribution Planning Model by Time and Cost Optimization -, The 22nd Annual Conference of Japan Society of Material Cycles and Waste Management, 2011.

[5] Naoya S., Hiroto T., Nobuyuki E. and Yoshikazu O., Development of a Disaster Waste Disposal Planning Model Aiming at Supporting of Appropriate Decision of Disaster Waste Treatment, Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research), Vol.74, Issue 5 ,2018, pp. I_195-I_202.

[6] Wakayama prefecture, Wakayama accident treatment of waste plan, 2015, https://www.pref.wakayama.lg.jp/prefg/031800/saigaikeikaku/saigaikeikaku.html, Accessed 2020/6/23.

[7] Wakayama city, Disaster waste disposal management plan for Wakayama city, 2017, http://www.city.wakayama.wakayama.jp/kurashi/gomi_kankyo/1001113/1001251/1018288/1018258.html, Accessed 2020/6/23.

[8] Ministry of the Environment, Guideline for disaster waste management, pp. Teq 14-4 - Teq 18-3, 2014, http://kouikishori.env.go.jp/guidance/download/, Accessed 2020/4/23.

[9] Okumura Corporation, Entrusted with the crushing and sorting of disaster waste in the Yamada area performance report, 2014.

[10] Statistics Bureau of Japan, Housing and Land Survey 2018 (e-stat), 2019, https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00200522&tstat=000001127155&cycle=0&year=20180&month=0&tclass1=000001129435&tclass2=000001129436&stat_infid=000031865682, Accessed 2020/06/29.

[11] Tokyo Metropolitan of Government Disaster Prevention Information, Damage assumption in Tokyo by Nankai Trough disastrous earthquakes (It's published on May 14, 2013.), pp.3-7, 2013, https://www.bousai.metro.tokyo.lg.jp/_res/projects/default_project/_page_/001/000/402/part3-4-2.pdf, Accessed 2020/4/23.

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