Optimal Truck Dispatching For Construction Waste Conveyance

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***Abstract*—Waste from the construction industry has to be conveyed to and disposed at specific waste-treatment plants. Decision makers, who work in environmental protection companies, usually schedule and dispatch the trucks used for conveying construction waste to plants manually, which is neither efficient nor effective. In practice, there are space and capacity limitations in every construction site and waste-treatment plant, meaning that the amount of the construction waste for transporting and disposing at a specific time and position is restricted. Moreover, when the number of trucks is insufficient, the responsible environmental protection companies could also hire vehicles from car rental companies. Given these considerations, coupled with the related operational constraints and objective of construction waste conveyance in practice, in this study we employ a time-space network flow technique to develop an optimal scheduling model that can assist decision makers in dispatching both their own and rented trucks for conveying construction waste efficiently. The model is formulated as an integer network flow problem with side constraints. Finally, a case study using the real data from an environmental protection company in Taiwan is performed and the results indicate that the model could be useful for dispatching trucks efficiently and thus decreasing the conveyance cost.**

***Index Terms*: construction waste; conveyance cost; truck dispatching; network flow; integer programming.**

I. INTRODUCTION

The reduction, recycling and reuse of waste materials is progressively being taken more seriously by every country in the world due to the depletion of the Earth's natural resources. Compared with households, the construction industry generates a great deal of waste each year. This large quantity of waste would have a great impact on the environment if there were no proper management or improvement policies for its disposal in place. However, construction waste such as concrete, tile, wood and glass can be processed and turned into construction material again. Therefore, the effective management plays an important role in reducing, recycling and reusing of construction waste.

There have been research studies devoted to the issue of improving construction waste management and developing suitable policies in the last decade. For example, Roche and Hegarty[1] proposed guidelines for promoting a coherent and integrated approach to the management of construction waste generated during a project process. The authors also sketched out the manner in which the participants of the project could work in co-operation to reduce the construction waste.

Kofoworola and Gheewala[2] noted that in Thailand, in the past, about 7.7% of the total amount of construction waste was disposed in landfills and dumpsites each year. The authors indicated that if construction waste management and recycling were implemented effectively, not only energy could be saved, but the resultant economic and social benefits would be considerable. Udawatta et al. [3] utilized both qualitative and quantitative research approaches to determine the five most crucial factors for effective waste management. Dahlbo et al. [4] employed four different methodologies, material flow analysis, life cycle assessment, environmental life cycle costing and the best available technology, to assess and evaluate the performance of a construction waste management system.

Mendis et al. [5] made use of the expert questionnaire survey, and evaluated the opinions by analytical hierarchy process (AHP) with attribute weighing method (AWM) to investigate the potential for waste generating in construction projects. Elizar et al. [6] used open questionnaire surveys to investigate the improving of performance level, which is collected and arranged the point of view from the experts, for waste construction management. Lu et al. [7-8] employed big data methods to benchmark and analyze the construction waste management performance. Other studies have utilized different approaches to advance the effectiveness of construction waste management (Gangolells et al. [9], Rodríguez et al.[10] and Butera et al.[11]).

In addition to reducing, recycling and reusing, construction waste most often needs to be conveyed to specific waste-treatment plants. In practice, the environmental authority in Taiwan is notified fora large-scale construction project with a substantial fund for submitting the proposal of waste conveyance by law to avoid the pollution caused by arbitrary dumping. Thus, managers of construction sites where a great amount of waste is generated have to contract with environmentalprotection companies to dispatch trucks for conveying and dumping the construction waste.

The Environmental protection company would assign its truck fleet on the basis of the request of every construction site applied on the previous day. However, in the aforementioned studies, the focus is on waste management, none have discussed how to schedule the trucks that carry the construction waste to the dump sites efficiently. In practice, most of these environmental protection companies dispatch their truck fleet manually, according to the demands at construction sites at given times. This way which is based on the experience of the

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decision makers is neither efficient nor effective, especially when there is a great deal of construction waste to be transported from many construction sites.

The literatures of vehicle dispatching and assignment have been discussed, e.g.,see Dantzig and Ramser [12],Rego and Roucairol [13], Vukadinović et al.[14] and Marković et al. [15].These studies basically considered the position of the demand places and focused on the route of the dispatched vehicles, ignoring the task executing time.Li et al. [16] modeled the truck scheduling for waste collection and transportation in a metropolis of Brazil to minimize the operating cost which is on the increase and balance the trip to all recycling facilities. Huang and Lin [17] proposed a bi-level model to optimize the area of the stopping point of the garbage truck fleet and minimize the traveling distance for collecting the household waste.

Other researches related vehicle routing include, e.g.,Yu et al.[18],Zhang et al. [19] and Hokama et al. [20]. Similarly, all of them arranged the vehicle routeswhere every place would be visited only once. Because of lacking timeconsideration, the models developed cannot be applied to the truck fleet dispatching problem in this study. In operations, trucks will be dispatched to construction sites at specified times to specific waste-treatment plants, carrying a certain amount of construction waste for achieving an economic goal, such as minimization of transportation cost.

Due to the space and capacity constraints in both construction sites and waste-treatment plants, there are limitations on the number of truckloads of construction waste conveyed and dumped. That is, the amount of construction waste transported cannot exceed the amount generated at a construction site at a given time. Similarly, the batch of construction waste needed to be dumped cannot exceed the capacity of the waste-treatment plant at a given time

.Consequently, these constraints will restrict the number of trucks for dispatching at a place with a specific time. In addition,if the number of vehicles is insufficient, more trucks can be rented from car rental companies. Thus, given the requirements of construction waste conveyance and dumping in practice, we employ a network flow technique and mathematical programming method to develop an optimization model, with the objective of minimizing the total conveyance cost, which can help decision makers dispatch both the own and rented trucks for conveying construction waste simultaneously and efficiently. The remainder of this paper is organized as follows. The modeling approach is described in Section II. Then, the numerical tests are discussed in Section III. Finally, some conclusions and suggestions are given in Section IV.

II. MODELING APPROACH

The time-space network could clearly represent vehicle and passenger movements in the dimensions of time and space. Compared with traditional methods for formulating NP-hard problems, this novel dynamic network flow technique could construct the models flexibly and solve the problems efficiently,even though more variables may require for modeling. For this reason, the time-space network technique has been successfully utilized in the transportation field for dispatching and scheduling problems (e.g., see Yan et al.[21-22]).

Therefore, a time-space network technique is employed to build the model used for optimally dispatching the truck fleet while minimizing the construction waste conveyance cost. Before introducing the model, several assumptions are made based upon information about the actual operations of an environmental protection company:

- The amount of construction waste on each site is given as a deterministic value. This is because the managers of construction sites have to report to the environmental protection company on the previous day about the amount of waste needed to be conveyed and dumped. In general, the construction waste generated in real time cannot be collected and dumped due to safety reasons in construction.
- Construction waste conveyance information, such as the amount of the waste to be transported from several certain construction sites and the maximum waste disposal ability of the given waste-treatment plants, is known.
- The fleet size of the company's own trucks is known. Personnel are included for both their own and rented trucks. Therefore, regardless of how much waste has to be dumped, the personnel cost associated with the truck fleet size is fixed.
- The planning period for the construction waste dumping and conveyance schedule is set to be one day. Trucks that start from the environmental protection company at the beginning of work time must go back to the company after duty.
- To ensure that construction waste is loaded immediately, all of the waste that needs to be transported should be collected respectively at each construction site before the trucks arrive. The travel time between each construction site and each waste-treatment plant is known.
- Related costs including the truck rental cost, payment of the waste-treatment plants, and other fixed costs associating with the truck fleet are given. Note that the cost of loading and unloading a truck is fixed regardless of the amount of waste.

The major components of the model containing the truck fleet-flow network and mathematical formulation are described below.

A. Truck Fleet-Flow Network

The time-space network technique is used for modeling the truck dispatching and scheduling, as shown in Fig. 1. The horizontal axis indicates the spatial dimension for denoting the car rental company, the environmental protection company, the construction sites and the waste treatment plants. The vertical axis shows the temporal dimension representing different time points during the planning period. The time interval between the nodes along this axis represents a time unit. The size of the

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time unit affects the accuracy of the model. The smaller the time unit is set, the more accurate the schedule is solved. However, the model will become more complex with a higher density of nodes and vice versa. The two major elements in the network are nodes and arcs.

The former, excluding the source/sink nodes for the environmental protection company as well as the renting/returning nodes for the car rental company, stand for a place at a specific time. The source and sink nodes of the environmental protection company, marked (10) and (11) in Fig. 1, represent the truck fleet supply and demand at the beginning and the end of the planning period, respectively. In situations where the number of vehicles is insufficient, trucks can be supplied from the renting node of the car rental company, marked (12) in Fig. 1, and should be returned to the returning node of the car rental company, marked (13) in Fig. 1. Both of these two nodes can be regarded as the external supply and external demand of the truck fleet respectively. Each arc can be deemed an activity for the trucks in the network. Nine types of arcs are defined below.

1) The Departure Arc

The departure arcs, marked (1) in Fig. 1, start at the source node of the environmental protection company and end at the construction site locations. This arc represents the start of the truck fleet dispatching. The arc cost, such as the personnel cost for servicing and driving a truck for one day service, and the operating cost such as the fuel for moving the truck from the source node to the construction site, is set. The arc flow's upper bound is infinity (or the company's fleet size plus the maximum number of vehicles that are allowed to rent from the car rental company), meaning the maximum number of available trucks that could be dispatched in one day. The arc flow's lower bound is zero, implying that there is no truck dispatched to execute the task.

2) The Holding Arc

A holding arc, marked (2) in Fig. 1, starts at a node associated with a place at a time point and ends at the other node associated with the same place but at a different time point. This arc represents the waiting of a truck at either a construction site or a waste-treatment plant in a time interval. The waiting does not generate any extra cost; therefore the arc cost is zero. Note that in long term operations, the depreciation cost of vehiclesshould be considered. However, in short term operations this cost can be regarded as a fixed cost, so it can be removed from the model. The arc flow's upper bound is infinity, indicating that all of the operational trucks could be held at the location during the specific time period. The arc flow's lower bound is zero, meaning that no truck is held at the location in this time period.

3) The Service Arc

A service arc, marked (3) in Fig. 1, starts at a construction site and ends at a waste-treatment plant. This arc represents the waste conveyed by the truck from the construction site to the plant. The arc cost includes the operating cost for the truck traveling from a construction site to a plant, the waste handling cost, and the waste disposal fee at the plant. The arc flow's upper bound is infinity, meaning that all trucks could be dispatched to convey construction waste. The arc flow's lower bound is zero when no truck is in operation.

4) The Ferry Arc

A ferry arc, marked (4) in Fig. 1, starts at a waste-treatment plant and ends at a construction site. This arc represents the movement of an empty truck from the waste-treatment plant to another construction site so that the truck can execute its task again. Compared with the service arc, the arc cost is only the operating cost for ferrying the empty truck from the waste-treatment plant to a construction site. The arc flow's upper and lower bound are the same as for the service arc.

5) The Collection Arc

The collection arcs, marked (5) in Fig. 1, start at the final nodes of all waste-treatment plants and end at the sink node for the environmental protection company. This arc represents the return of the truck fleet back to the environmental protection company upon completion of their task. The arc cost is the operating cost such as the cost of the fuel for moving the truck from the waste-treatment plant to the environmental protection company. The arc flow's upper bound is infinity, meaning that all of the dispatched trucks could return to the environmental protection company. The arc flow's lower bound is zero.

6) The Non-Service Arc

The non-service arc, marked (6) in Fig. 1, connects the source and sink nodes of the environmental protection company. The arc denotes the number of trucks that are not dispatched for construction waste conveyance.Because there is no cost incurred when a truck is not dispatched, the arc cost is zero. The arc flow's upper bound is the fleet size, and indicates the number of trucks not dispatched. The arc flow's lower bound is zero, implying that all of the trucks are dispatched to execute the task.

7) The Renting Arc

The renting arc, marked (7) in Fig. 1, connects the renting node of the car rental company and the source node of the environmental protection company. This arc represents the number of trucks that have to be hired to execute the task. The cost is the charge for renting a truck. It is worth mentioning that every rented truck has its crew, and the payment for the rented truck includes their salary. Therefore, no extra fee has to be paid for hiring staff to operate the rental truck. The arc flow's upper bound is infinity, indicating that there is no limit to the number of trucks that can be rented. The arc flow's lower bound is zero, meaning that no truck is rented.

8) The Non-Renting Arc

The non-renting arc, marked (8) in Fig. 1, connects the renting and returning nodes of the car rental company. In contrast to the truck renting arc, this arc indicates that the environmental protection company does not need to rent

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external trucks to execute the task when there is a sufficient number of vehicles. The arc cost is zero, and both the arc flow's upper and lower bound are identical to those of the truck renting arc.

9) The Returning Arc

The returning arc, marked (9) in Fig. 1, connects the sink node of the environmental protection company to the returning node of the car rental company. This arc represents the return of rented trucks to the car rental company. The arc cost is also zero. The arc flow's upper bound is infinity, implying that all of the rented trucks could be returned to the car rental company. The arc flow's lower bound is zero.

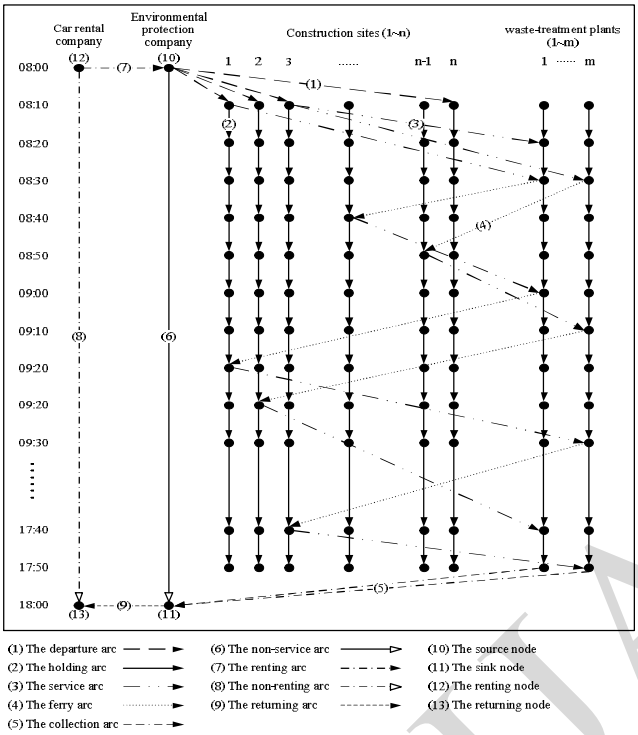


Fig. 1: Truck fleet-flow network

B. Model Formulation

Based on the truck fleet-flow time-space network mentioned above, coupled with flow conservation constraints and the related operating constraints of the construction waste conveyance in actual operations, the model is formulated as an integer network flow problem with side constraints. The notations and symbols used in the model and the mathematical model are described below.

1) Notations and Symbols Used in the Model

Decision variable:

x_{ij} : The arc (i,j) flow;

Parameters:

c_{ij} : The arc (i,j) cost, relating with the fixed, operational and truck rental costs;

b_i : The supply and demand for node i. Note that if node $i$is the source/sink node of the environmental protection company, b_i is equal to the truck fleet. If node $i$is the renting/returning node of the car rental company, this value is the maximum number of trucks that are allowed to rent. However, if node $i$is another node in the network, it is regarded as a transfer node, then b_i is set to be 0;

d^s : The demand (in truckloads)for the s^{th} construction site;

p_j^d : The maximum number of truckloads for the construction waste disposal associated with the d^{th}waste-treatment plant at the j^{th} node;

t_i^s : The maximum number of truckloads for the construction waste conveyance associated with the s^{th}construction site at the i^{th} node.

Sets:

S : The set of the supply nodes, including the source node of the environmental protection company and the renting node of the car rental company;

T : The set of all transfer nodes;

D : The set of the demand nodes, including the sink node of the environmental protection company and the returning node of the car rental company;

N : The set of all nodes;

A : The set of all arcs;

F : The set of all construction sites;

AO_i : The set of the service arcs emanating from node i;

AI_j : The set of the service arcs pointing to node j;

A^s : The set of the service arcs associated with the s^{th} construction site;

W^s : The set of the nodes associated with the s^{th} construction site;

W^d : The set of the nodes associated with the d^{th} waste-treatment plant;

2) Mathematical Model

The model is designed as an integer network flow problem with side constraints, with the objective of minimizing the total conveyance cost. The model is formulated as follows:

Minimize:

$$\sum_{ij\in A} c_{ij}x_{ij} \tag{1}$$

Subject to:

$$\sum_{j\in N} x_{ij} - \sum_{k\in N} x_{ki} = \begin{Bmatrix} b_i & ,i\in S \\ 0 & ,i\in T \\ -b_i & ,i\in D \end{Bmatrix}; \tag{2}$$

$$\sum_{ij\in AO_i} x_{ij} \le t_i^s, \qquad \forall i\in W^s, \forall s\in F; \tag{3}$$

$$\sum_{ij\in AI_j} x_{ij} \le p_j^d, \qquad \forall j\in W^d, \forall d\in D; \tag{4}$$

$$\sum_{ij\in A^s} x_{ij} \ge d^s, \qquad \forall s\in F; \tag{5}$$

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$$x_{ij} \geq 0, \qquad x_{ij} \in INT, \forall ij \in A; \qquad (6)$$

Equation (1) is the objective function for minimizing the total conveyance cost, including the fixed, operational and truck rental costs. Equation (2) ensures the flow conservation for the supply nodes, the demand nodes and the transfer nodes.

Equation (3) limits the maximum number of truckloads for the construction waste conveyance associated with the s^{th} construction site at the i^{th} node. Similar to the previous equation, equation (4) constrains the maximum number of truckloads for the construction waste disposal associated with the d^{th} waste-treatment plant at the j^{th} node. Equation (5) guarantees that the sum of the service flows associated with every construction site should suffice for its demand. Equation (6) ensures that all arc flows are non-negative integers.

III. NUMERICAL TEST

To demonstrate the performance and applicability of the proposed model, a case study based on the operational data from an environmental protection company in Taiwan is tested. The required input data from actual operations were first analyzed. Then, the necessary programs to solve the problem with the proposed model were written using the C++ computer language, coupled with the mathematical programming CPLEX 11.1. The numerical tests were executed on an Intel Core i7-3.4GHz CPU with 8GB RAM using Microsoft Windows 7 as the operating system. Finally, sensitivity analyses of important parameters in the model were performed to understand their effects on the solutions.

A. Data Analysis

The operating data were sourced from an environmental protection company in Taiwan. All the required data are listed in Table 1. The company with a fleet of 15 trucks serves 30 construction sites, conveying and dumping construction waste at two waste-treatment plants. There is also a car rental company which can supply extra trucks when the number of vehicles is insufficient. The planning period in this case study is from 8:00 to 18:00, 10 hours. All of the trucks should leave the environmental protection company at the start time to execute the assignment, and go back there at the ending time when work is finished. The time interval between two nodes is set to be 10 minutes giving a total of 61 nodes alone the temporal axis in the network. It is worth mentioning that this time interval is determined according to the characteristics of the specific problem but could be adjusted for applying to other cases.

Table I. Required Data

Truck fleet (vehicles)		15
Construction sites		30
Waste-treatment plans		2
Planning period		8:00-18:00
Average speed (km/h)		20
Cost	salary of the crew (NT$/vehicle)	2,212
	waste disposal fee (NT$/vehicle)	2,200
	fuel cost (NT$/km/vehicle)	16.73
	truck rental cost (NT$/vehicle)	3,300

All positions of the construction sites as well as the waste-treatment plant locations from which to calculate the average travel time between two places, at an average speed of 20 km/h, are given. The demands of all construction sites are given. In addition, all cost parameters in the truck fleet-flow time-space network are obtained. In particular, the salary of the crew is regarded as a fixed cost NT$ (New Taiwan Dollar) 2,212 per truck. The operating costs such as the waste disposal fee at the waste-treatment plant and the fuel cost per truck are set to be NT$ 2,200/vehicle and NT$ 16.73/km, respectively. The truck rental cost is NT$ 3,300/vehicle.

B. Preliminary Result Analysis and Discussion

The proposed model contains 1,922 nodes, 9,273 arcs and 16,959 constraints, in which 1,922 constraints ensure flow conservation at each node, 9,273 constraints guarantee the integers for all arc flows, and 5,764 side constraints satisfy the operational requirements in practice.

The preliminary test results are listed in Table 2. The objective value is NT$ 472,727, taking 3.04 seconds. 183 truck trips are dispatched to satisfy the demands of all construction sites, with no idle trucksat the environmental protection company. Moreover, the company's fleet size is large enough to meet demand, so that there is no need to rent trucks from the car rental company. The distribution of the total cost in Table 3 indicates that the operational cost, accounting for 93 percent of the total cost, is the highest cost compared with the other two. In particular, the waste disposal fee is 85 percent, whereas the fuel cost is only 8 percent. The fixed cost is 7 percent and there is no truck rental cost.

Table II. Test Results

Objective value (NT$)	472,727
Solution time (seconds)	3.04
# of truck trip dispatches (truckloads)	183
# of rented trucks (vehicles)	0
# of idle trucks (vehicles)	0

Table III. Distribution of the Total Cost

Cost item	description	NT$	Proportion (%)
Operational cost	Waste disposal fee	402,600	85%
	Fuel cost	36,947	8%
Fixed cost	Crew salary	33,180	7%
Truck rental cost	Rental	0	0%

In practice, the decision makers dispatch trucks based on their own experiences with the general rules described as follows. The number of trucks to dispatch is set according to

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the amount of the waste reported in advance. When the number of trucks is insufficient, more trucks are rented for assisting in conveying construction waste. The construction sites with more waste to convey and/or neighboring the waste-treatment plants are given higher priority to dispatch trucks. Moreover, trucks are dispatched to execute the task at a construction site until the work is finished. They are then switched to the next site to execute the task again. Based on the above rules, the decision maker of the studied environmental protection company was invited to manually solve the test problem for a couple of times.

It took the decision maker, who is a senior staff in this field, about 120 minutes each time to manually solve the problem, and the solutions were always worse than that obtained from the proposed model. It is certain that the decision maker will take more time to solve large scale problems in practice, let alone a junior staff. Consequently, the conventional method is very inefficient to generate a truck dispatching plan in practice. Moreover, a decision maker may make different decisions at different times, indicating that the manual solutions, obtained depending on the decision maker's own experience, are not stable, mostly being inferior. In contrast to the conventional method, the proposed model considers all resources and requirements systematically and can always yield an optimal truck dispatching plan that assists the decision maker in assigning trucks among construction sites and waste-treatment plants at suitable times at a minimum cost. As a result, the proposed model outperforms the conventional method in terms of solution efficiency, effectiveness and stability, and therefore is potentially useful in practice.

C. Sensitivity Analysis

To comprehend the effect of the essential input parameters on the objective value, sensitivity analyses for the truck fleet size, fuel cost as well as the waste disposal fee, were conducted.

The solutions are described below.

1) The Truck Fleet Size

The sensitivity to the truck fleet size, ranging in size from 0, 5, 10, 14, 15 and 16 vehicles, can be seen by inspecting the results and the solutions summarized in Table 4. The results show that the objective values, except for the 16 vehicle fleet size, decrease as the fleet size increases. In particular, the loss deceases as the fleet size increases. Note that with the same construction site demand, 15 vehicles are enough to execute the task in this case. Consequently, if there are less than 15 trucks, the company should rent vehicles from the car rental company, so that the rental portion of the total cost increases. However, when there are more than 15 trucks, the rest of the vehicles would sit idle at the company. This is why the total cost does not increase when the fleet size increases to more than 15 trucks.

Table IV. Sensitivity Analysis for Truck Fleet Size

Truck fleet size	0	5	10
Objective value (NT$)	522,262	505,727	489,230
# of rented truck (vehicles)	15	10	5
# of idle truck (vehicles)	0	0	0
Solution time (seconds)	1.61	2.82	6.69
Difference to original value (%)	10.48%	6.98%	3.49%
Truck fleet size	14	15	16
Objective value (NT$)	476,028	472,727	472,727
# of rented truck (vehicles)	1	0	0
# of idle truck (vehicles)	0	0	1
Solution time (seconds)	1.68	3.04	3.68
Difference to original value (%)	0.70%	0.00%	0.00%

2) The Fuel Cost

The sensitivities of the fuel cost, ranging from 80% to120% of the original fuel cost, are tested and the solutions are summarized in Table 5. The solutions show that the fuel cost affects the objective value positively and slightly. When the fuel cost decreases to 80%, the objective value is lowered to NT$ 465,314 (from NT$ 472,727); in other words, it is decreased by 1.57%. On the other hand, when the fuel cost increases to 120%, the objective value is raised to NT$ 480,180 (from NT$ 472,727), with an increment of 1.58%.

Table V. Sensitivity Analysis for Fuel Cost

Fuel cost	80%	90%	100%	110%	120%
Objective value (NT$)	465,314	469,080	472,727	476,494	480,180
Solution time (seconds)	5.04	5.88	3.04	2.50	7.32
Difference to original value (%)	-1.57%	-0.77%	0.00%	0.80%	1.58%

3) The Waste Disposal Fee

The waste disposal fee accounts for a large proportion of the total cost and consequently significantly affects the objective value. The sensitivity of the waste disposal fee is tested, using values ranging from 80% to 120% of the original waste disposal fee. The results are listed in Table 6. Similar to the fuel cost sensitivity, the solutions show that the total cost increases as the waste disposal fee increases. When the waste disposal fee decreases from 90% to 80%, there is a significant reduction in the objective value from 8.52% to 17.03% of the original value. In contrast, when the fee increases from 110% to 120%, there is a significant increase in the objective value from 8.52% and 17.03% of the original value. This result provides a reference for the environmental protection company when choosing the waste-treatment plants. Note that the objective values are proportional to the waste disposal fee, so, for example, when the fee increases/decreases by 10%, the total cost increases/decreases by 8.52%.

Table VI. Sensitivity Analysis for Waste Disposal Fee

Waste disposal fee	80%	90%	100%	110%	120%
Objective value (NT$)	392,215	432,469	472,727	512,996	553,252
Solution time (seconds)	7.38	5.88	3.04	4.79	11.05
Difference to original value (%)	-17.03%	-8.52%	0.00%	8.52%	17.03%

IV. CONCLUSIONS

In this study, an optimization model is developed using the time-space network technique to solve truck dispatching

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problems for the conveyance of construction waste. Based on the flow conservation constraints, coupled with the requirements of the construction waste disposal and conveyance applied in practice, the model is formulated as an integer network flow problem with side constraints. The proposed model is aimed at minimizing the total conveyance cost, given the limited capacity of construction waste conveyance vehicles. Numerical tests are then performed to evaluate the model, using real data from an environmental protection company in Taiwan.

The preliminary results show that the model is able to dispatch the truck fleet efficiently and thus decrease the construction waste conveyance cost for the environmental protection company. Next, some important parameters of the model are investigated in the sensitivity analyses, to demonstrate their influence on the construction waste conveyance cost. Furthermore, the model parameters can be revised flexibly for future applications. Finally, while a systematic optimization model considering deterministic demands and travel times is proposed in the study, a more complicated model could be developed based on the proposed model in the future, to cope with the uncertainty in demands and travel times for construction waste conveyance that often occur in actual operations.

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REFERENCES

[1] Roche, D. andHegarty, S.,Best practice guidelines on the preparation of waste management plans for construction and demolition projects, 2006. http://www.envirocentre.ie/includes/documents/BPGConstructionand%20demolition.pdf. Accessed 24 May 2016.

[2] Kofoworola, O.F. andGheewala, S.H., "Estimation of construction waste generation and management in Thailand",*Waste Management*, 2009,Vol. 29, No. 2,pp. 731-738.

[3] Udawatta, N.,Zuo, J.,Chiveralls, K. andZillante, G., "Improving waste management in construction projects: An Australian study",*Resource, Conservation and Recycling*, 2015,Vol. 101, pp. 73-83.

[4] Dahlbo, H.,Bachér,J.,Lähtinen,K.,Jouttijärvi, T.,Suoheimo,P.,Mattila,T.,Sironen, S.,Myllymaa, T. andSaramäki, K., "Construction and demolition waste management – a holistic evaluation of environmental performance",*Journal of Cleaner Production*, 2015, Vol.107, pp.333-341.

[5] Mendis, D.,Hewage, K.N. andWrzesniewski J., "Contractual obligations analysis for construction waste management in Canada",*Journal of Civil Engineering and Management*, 2015,Vol. 21, No. 7,pp. 866-880.

[6] Elizar,Wibowo, M.A. andKoestalam P., "Identification and Analyze of Influence Level on Waste Construction Management of Performance",*Procedia Engineering*, 2015, Vol.125, pp.46-52.

[7] Lu, W., Chen,X.,Peng,Y. andShen L.,"Benchmarking construction waste management performance using big data", *Resource, Conservation and Recycling*, 2015, Vol. 105, pp. 49-58.

[8] Lu, W., Chen, X., Ho, D.C.W. and Wang H., "Analysis of the construction waste management performance in Hong Kong: the public and private sectors compared using big data",*Journal of Cleaner Production*, 2016, Vol. 112, No. 1, pp. 521-531.

[9] Gangolells, M., Casals, M.,Forcada, N. andMacarulla M., "Analysis of the implementation of effective waste management practices in construction projects and sites",*Resources, Conservation and Recycling*, 2014, Vol.93, pp.99-111.

[10] Rodríguez, G.,Medina,C.,Alegre, F.J.,Asensio, E. andSánchez de Rojas M.I., "Assessment of Construction and Demolition Waste plant management in Spain: in pursuit of sustainability and eco-efficiency",*Journal of Cleaner Production*, 2015, Vol. 90,pp. 16-24.

[11] Butera, S., Christensen,T.H. andAstrup, T.F., "Life cycle assessment of construction and demolition waste management",*Waste Management*, 2015, Vol.44, pp.196-205.

[12] Dantzig, G.B. andRamser, J.H., "The truck dispatching problem", *Management Science*, 1959, Vol.6, No. 1, pp.80-91.

[13] Rego, C. andRoucairol, C., "Using Tabu search for solving a dynamic multi-terminal truck dispatching problem",*European Journal of Operational Research*, 1995, Vol. 83, No. 2, pp. 411-429.

[14] Vukadinović, K.,Teodorović, D. andPavković, G., "An application of neurofuzzy modeling: The vehicle assignment problem",*European Journal of Operational Research*, 1999,Vol. 114, No. 3, pp. 474-488.

[15] Marković, N.,Drobnjak,Ž. and Schonfeld P., "Dispatching trucks for drayage operations",*Transportation Research Part E: Logistics and Transportation Review*, 2014, Vol. 70, pp. 99-111.

[16] Li, J.Q.,Borenstein, D. andMirchandani, P.B., "Truck scheduling for solid waste collection in the City of Porto Alegre, Brazil",*Omega*, 2008, Vol. 36, No. 6, pp. 1133-1149.

[17] Huang, S.H. and Lin, P.C., "Vehicle routing-scheduling for municipal waste collection system under the "Keep Trash off the Ground" policy",*Omega*, 2015, Vol. 55, pp. 24-37.

[18] Yu, B., Yang, Z.Z. and Yao, B., "An improved ant colony optimization for vehicle routing problem",*European Journal of Operational Research*, 2009, Vol. 196, No. 1, pp. 171-176.

[19] Zhang, J., Zhao, Y.,Xue,W. and Li, J., "Vehicle routing problem with fuel consumption and carbon emission",*International Journal of Production Economics*, 2015, Vol. 170, pp. 234-242.

[20] Hokama, P., Miyazawa, F.K. and Xavier, E.C., "A branch-and-cut approach for the vehicle routing problem with loading constraints",*Expert Systems with Applications*, 2016, Vol.47, pp. 1-13.

[21] Yan, S., Hsiao, F.Y. and Chen, Y.C., "Inter-school bus scheduling under stochastic travel times",*Networks and Spatial Economics*, 2015, Vol. 15, No. 4, pp. 1049-1074.

[22] Yan, S., Wang, W.C., Chang, G.W. and Lin, H.C., "Effective Ready Mixed Concrete Supply Adjustments with Inoperative Mixers under Stochastic Travel Times", *Transportation Letters*, 2016, Vol. 8, pp. 286-300.

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