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Original Research Paper

Research on the Location and Allocation Strategy of the Construction of Waste Resource Center Based on Environment Protection

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ABSTRACT

Urban construction and environment protection are important contents in the urban regeneration. The output of the construction waste is very huge, which has serious impacts on the ecological environment and the urban land use during the urban regeneration process. This paper establishes a mathematic strategy model of the location, capacity and allocation of the construction waste resource center, without considering the landfill for the disposal of the construction waste, which was the basic recycling disposal method of the construction waste. Then, in aspect of solving the mathematical model, it is proposed to adapt basic simulated annealing algorithm with two stages improvement to solve the model, which is also controlled in urban construction experience data. Results of the case simulation show that the mathematical model and the solving method are suitable to the limited number of the construction waste resource center model, which can be the references to the problem of urban construction and environment protection in the urban regeneration.

INTRODUCTION

The rapid growth of the waste material has significant effects on social management, economic development and environment protection. Construction waste is one kind of waste materials, and the largest part of the solid waste materials in the city, which consists of waste concrete, waste clay and waste timber and so on. These waste materials are generally brought out during the progress of the demolition, construction and mining or repair towards various kinds of buildings, underground facilities and the pipe network. Recently, because of the sharp increase of urban construction, collection and disposal of construction waste has become a significant burden on the city. Then, due to the huge generation amount of construction waste, the traditional method of construction waste processing is in urgent need of improvement, which now is just the landfill and causes problems of land resources occupation, soil pollution, and the serious damage to the environment. With the development of construction waste research, it is pointed out that most of the construction waste can be recycled by sorting, excluding or crushing or to be reused. Therefore, the government actualizes the policy of waste resource reclaim so as to ease the resource and environmental pressure. Considering the processing cost and distributed convenience of the construction waste, it is suggested to establish a few construction waste resource centres in a city, which are the facilities of construction waste reclaim for the production of recycled construction materials. Facility location of the construction waste resource center usually involves multiple and conflicting objectives, and attributed to the problem of the network facility location, model solving algorithm of which usually is the multi-objective evolutionary algorithm (Lokeshwari et al. 2011).

Meanwhile, researches on waste collection and utilization are mostly in vehicle routing problem or simple location analysis. BrimBerg and ReVelle solved the location model by weighted method through the establishment of dual target location model considering the minimum cost and comprehensive service (Brimberg 1998). Angelelli E and Speranza M G. proposed the PVRP-IF model for vehicle routing optimization in the analysis of different processing patterns of the waste collection (Angelelli 2002). Fernandez & Puerto (2003) established the multi-objective optimization model and obtained approximate optimal Pareto solution by means of dynamic programming, which decomposed the problems. Lv et al. (2005) studied both the location of solid waste recycling station and the arrangement of the transportation routes of the waste material from the angle of system theory, and then established a location and path planning model using two stages Tabu searching heuristic algorithm to solve the model. Chang & Eric (2006) presented an innovative optimization model using the grey mini-max regret integer programming algorithm to outline an optimal regional coordination of solid waste routing and possible landfill/incinerator construction under an uncertain environment. He & Ren (2006) studied the station location, processing capacity and the points of the waste generation allocated to the corresponding station location, established a model based on the minimum total cost and negative utility and proposed a hybrid multi-objective evolutionary algorithm. Drezner (2009) and Haiy (2012) proposed a negative effect measure method based on the diffusion distance, which researched on three layer logistics network of the urban wastes, established a mixed integer programming model, and designed a hybrid algorithm combined the simulated annealing algorithm and greedy algorithm for solving the multi-objective decision.

PROBLEM DESCRIPTION

The location problem is a kind of very difficult problems in optimization. From 1950s, facility location has been a focus research field in management science and operations research. Different from the traditional processing method of the urban solid waste materials by collection, transportation and dumping, the construction waste is not completely useless waste, which can be used to produce meaningful building materials by resource recycling utilization. In the places of high intensive urban construction areas, construction waste is a major source of building materials for regeneration, which can be used in the new urban construction projects. A typical construction waste resource distribution network can be described as Fig. 1.

Furthermore, different from the problem of the urban solid waste transfer station location, which can be described as many to one, location of the construction waste resource center is a problem which can be described as many to many. Because, the quantity and the volume of the construction waste are very huge, there is generally no transfer problem, and will be directly sent into the recycling center for renewable materials production until the formation of products to the dispersed demand areas. In

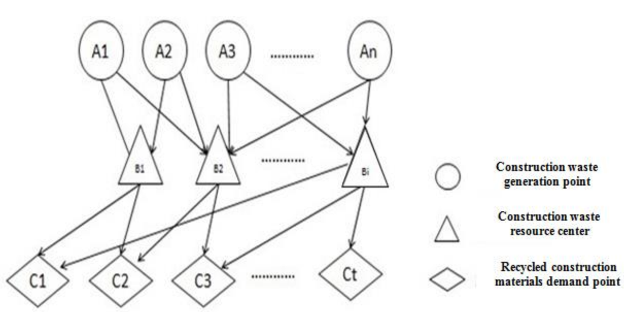

Fig. 1: Construction waste resource distribution network.

the aspect of the target selection, the construction cost and transportation cost are key factors affecting the construction waste resource center planning, which the smaller the better. Meanwhile, due to the problems of urban development and environment protection, the construction waste resource center needs to be far away from the urban daily lifework area, which the farther the better. In addition, under the situation of the processing ability restriction of the construction waste resource center and the metabolic supply of the construction waste, if too much of the construction waste is delivered to a resource center, which is more than its processing capacity, it will cause additional cost. Therefore, it is necessary to consider the resource capacity and the service scope selection.

Above all, the position of the construction waste resource center, processing capacity, environmental impact and the transportation problems of the construction waste and recycling construction building materials should be comprehensively considered during the location planning of the construction waste resource center. The main research contents of this paper include the feasible location, probe progressing capacity and reasonable service scope of the construction waste resource center.

MODEL ESTABLISHMENT

Model assumptions: A waste material management program often involves conflicting economic, environmental and socio-ecological impacts (Cheng & Huang 2003). In this paper, it is suggested a strategy location model named location and capacity optimization model (LCOM). Assumptions of the model are as follows:

1. Distributed transportation costs of the construction waste and the recycling building materials are related to the distance, and the disposal cost of the construction waste is related to the amount of construction waste.
2. Landfill disposal is not considered.
3. Recycling building materials will be demanded before, and the warehousing cost is not considered.
4. Transportation and the location meet the urban planning and environmental requirements.

Parameters definition: Parameters in the strategy model of the construction waste resource center (LCOM) include the follows indicated in Table 1.

LCOM model establishment: In the selection of construction waste resource center, while allocating the transportation for the waste recycling, the first thing to be considered is how to reduce the total costs effectively, including the direct construction cost, distributed transportation cost and the other penalty costs.

Table 1: Parameters in the model.

Parameters	Definition
i	construction waste generation point, $i \in I(i = 1, 2, 3, \ldots\ldots, n)$
j	construction waste resource center, $j \in J(j = 1, 2, 3, \ldots\ldots, k)$
h	recycling building materials demand point, $h \in H(h = 1, 2, 3, \ldots\ldots, \theta)$
d_{ij}	distance between construction waste generation point i and construction waste resource center j, (km)
d_{jh}	distance between construction waste resource center j and recycling building materials demand point h (km)
Q_i	construction waste amount of the construction waste generation point i ,(ton)
Q_{ij}	the construction waste amount from construction waste generation point i to construction waste resource center j, (ton)
X_{ij}	distribution ratio of the construction waste generation point i , $x_{ij} = \frac{Q_{ij}}{Q_i}$
Q_j	total production amount of the recycling building materials in construction waste resource center j, $Q_j = f(Q_i) = \rho Q_i$, ρ is the utilization coefficient
Q_{jh}	the recycling building materials amount from construction waste resource center j to recycling building materials demand point h, (ton)
Y_{jh}	distribution ratio of the construction waste resource center j, $y_{jh} = \frac{Q_{jh}}{Q_j}$
p	unit transportation cost of the construction waste and the recycling building materials, (dollar per ton.km)
w	unit disposal cost of the construction waste in the resource center, (dollar per ton)
C_j	rated processing capacity of the construction waste resource center j, (ton)
$C_j^{\max}$	maximum processing capacity of the construction waste resource center j (ton)
$C_j^{\min}$	minimum processing capacity of the construction waste resource center j ,(ton)
γ_j	maximum penalty cost if the amount of the construction waste outnumbers the max processing capacity of the construction waste resource center j
β_j	maximum penalty cost if the amount of the construction waste is less than the min processing capacity of the construction waste resource center j

***Capacity and direct construction cost*:** Direct construction cost of the construction waste resource center j cost t_1 is a function of construction scale which can be judged by the capacity. Then, set

$$\cos t_1 = \sum_{j=1}^{k}[\alpha f(C_j) + C_0] \qquad \ldots(1)$$

$$s.t.\ \alpha > 0 \qquad C_o \geq 0 \qquad \ldots(2)$$

Where $f(C_j)$ represents that direct construction cost is a function of construction scale. α is a cost coefficient of the construction scale, which represents the increasing cost following the increase of the construction waste resource center processing capacity. C_o is a fundamental construction cost.

***Construction waste disposal cost*:** In this paper, the construction waste disposal cost is considered under the uncertain condition, which mostly comes from the supply uncertainty of the construction waste.

Suppose there are i construction waste generation points, if the construction waste is distributed to the construction waste resource centre j nearby according to the principle of proximity, it may outnumber the maximum processing capacity of the center j although it can save the transportation cost. Conversely, it may be less than the minimum processing capacity of the construction waste resource center j. No matter which kind of the cases appear, it will affect the disposal cost of the construction waste resource center.

When select resource center in terms of reducing the comprehensive transportation cost of construction waste, if the total amount of the construction waste, which is delivered to the construction waste resource center j from all construction waste generation points, outnumbers the maximum processing capacity or is less than the minimum processing capacity of the center j, a cost should be paid for the center j, which is a penalty cost for the supply of the construction waste increase or decrease and it is named and respectively.

$$\cos t_2 = \sum_{j=1}^{k}\beta_j\left(\frac{\sum_{i=1}^{n}Q_{ij} - C_j^{\min}}{C_j^{\min}}\right) = \sum_{j=1}^{k}\beta_j\left(\frac{\sum_{i=1}^{n}x_{ij}Q_i - C_j^{\min}}{C_j^{\min}}\right) \qquad \ldots(3)$$

$$s.t.\ \sum_{i=1}^{n}Q_{ij} \leq C_j^{min} \qquad \ldots(4)$$

$$\cos t_3 = \sum_{j=1}^{k}\gamma_j\left(\frac{C_j^{\max} - \sum_{i=1}^{n}Q_{ij}}{C_j^{\max}}\right) = \sum_{j=1}^{k}\gamma_j\left(\frac{C_j^{\max} - \sum_{i=1}^{n}x_{ij}Q_i}{C_j^{\max}}\right) \qquad \ldots(5)$$

$$s.t.\ \sum_{i=1}^{n}Q_{ij} \geq C_j^{\max} \qquad \ldots(6)$$

Moreover, the basic disposal cost is needed for the waste concrete, waste clay and waste timber and so on, which is related to the amount of the waste. Set as t_4,

$$\cos t_4 = w\sum_{i=1}^{n} Q_i \quad ...(7)$$

$$s.t.\ w > 0 \quad ...(8)$$

***Transportation costs*:** Transportation costs include the transportation cost of the construction waste and the transportation cost of the recycling building materials, which are both related to the distance and the amount. Denote the transportation cost as cost t_5,

$$\begin{aligned}\cos t_5 &= p(\sum_{i=1}^{n}\sum_{j=1}^{k} Q_{ij}d_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{k} Q_{jh}d_{jh}) \\ &= p[\sum_{i=1}^{n}\sum_{j=1}^{k} x_{ij}Q_i d_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{k} y_{jh} f(Q_i) d_{jh}] \\ &= p(\sum_{i=1}^{n}\sum_{j=1}^{k} x_{ij}Q_i d_{ij} + \sum_{i=1}^{n} y \sum_{j=1}^{k} Y_{jh}\rho Q_i d_{jh})\end{aligned} \quad ...(9)$$

$$s.t.\ 1 > \rho > 0 \quad ...(10)$$

$$x_{ij} \geq o \qquad \sum_{j=1}^{k} x_{ij} = 1 \quad ...(11)$$

$$y_{jh} \geq 0 \qquad \sum_{h=1}^{\theta} y_{jh} = 1 \quad ...(12)$$

$$d_{ij} \geq D_T > 0, \qquad d_{jh} \geq D_T > 0, \quad ...(13)$$

Where, $f(Q_i)$ represents the function between the amount of recycling building materials and the construction waste generation amount. ρ is a recycling rate coefficient. D_T is an environmental distance constant, which represents that if the location point is out of the D_r, it is thought that the location point meets the environmental restrictions.

According to the description and the analysis above, the location and capacity optimization model of the construction waste resource center (LCOM model) can be established as follows:

$$R = \cos t_1 + \cos t_2 + \cos t_3 + \cos t_4 + \cos t_5 + \sum_{j=1}^{k} TU_j \quad ...(14)$$

Where TU_j represents the environment utility level, which is to judge the environmental impact of the construction waste resource center towards the urban residents' living and working condition. The distance between the construction waste resource center and the urban activity district, the farther the smaller of the influence, and the higher of the environment utility level of the urban residents.

In order to reduce the environmental impact, the distance restriction of the resource center location is required in the urban planning, which can be indicated by formula (13). Then, the LCOM model proposed in this paper can be revised as:

$$\begin{aligned}\min R &= \min(\cos t_1 + \cos t_2 + \cos t_3 + \cos t_4 + \cos t_5) \\ &= \sum_{j=1}^{k}[\alpha f(C_j) + C_0] + \sum_{j=1}^{k}\beta_j(\frac{\sum_{i=1}^{n} x_{ij}Q_i - C_j^{\min}}{C_j^{\min}}) + \sum_{j=1}^{k}\gamma_j(\frac{C_j^{\max} - \sum_{i=1}^{n} x_{ij}Q_i}{C_j^{\max}}) \\ &+ w\sum_{i=1}^{n} Q_i + p(\sum_{i=1}^{n}\sum_{j=1}^{k} x_{ij}Q_i d_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{k} y_{jh}\rho Q_i d_{jh})\end{aligned} \quad ...(15)$$

SOLVING THE MODEL

According to the model established in this paper, it consists of the location, capacity and the distribution of the construction waste decisions. This is an overall optimization problem. Simulated annealing algorithm (SA), which is suggested by N Metropolis firstly in 1953, is regarded as a suitable method to solve this kind of problem, especially in the field of combinatorial optimization. It can be used to avoid the local minimum solution and with multistep calculation to search the optimal solution.

Simulated annealing algorithm uses the Metropolis algorithm to achieve the overall optimization goal based on the similarity between solving of optimization problem and the annealing process of physical systems, which basic criterion is also called Metropolis criterion and can be described as follows (Chen Huagen 2004).

Suppose the temperature is T, particle stop state r satisfies with the Boltzmann probability distribution ($\Pr(E(r)) = \frac{1}{Z(T)}\exp[-\frac{E(r)}{k_b T}]$), where $E(r)$ is the energy of status r, $k_b > 0$ as a Boltzmann constant, T is the absolute temperature, normalized factor of probability distribution is $Z(T)$ described as $Z(T) = \sum_{s\in D}\exp[-\frac{E(s)}{k_b T}]$. Set the initial state i as the current state, where the state energy is E_i. Then, put a random disturbance towards the state i, and obtain a new state j, where the state energy is E_j. If $E_j < E_i$, then the state j is the important state. If, $E_j < E_i$ whether state j is the important state should be judged by the probability of the state j. Ratio of state i and state j is equal to the ratio of the corresponding Boltzmann factor, which is $r = \exp[(E_i - E_j)/k_b T]$, $r < 1$.

For the model solving, SA repeats the process of generating new solution, calculating objective function D-value, determining whether to accept the new solution and accepting or refusing the new solution, from the beginning of initial solution selected, by utilizing the new solution generation device and acceptance of the criteria. And then, repeat the current iteration to achieve the optimal execution process of the objective function. The solving steps are as follows (Zhu Haodong 2009).

Step1: Calculate the value of the objective function $f(\delta_0)$ and select the initial controlling temperature and the Markov chain length, from any initial state δ_0 in the feasible solution space optionally.

Step 2: Set a random disturbance in the feasible solution space and a new state δ_1, then, calculate the value of $f(\delta_1)$.

Step 3: According to the state acceptance function to decide the acceptance, if $f(\delta_1) < f(\delta_0)$, accept the new state δ_1 as the current state. Otherwise, decide whether accept according to the Metropolis criterion. If accept the situation, then set the current state as, if not, set the current state as.

Step 4: Decide whether stop the sampling process according to the criterion of convergence. If stop the sampling process, then turn to step 5. If not, turn to step 2.

Step 5: Reduce the controlling temperature *T* according to the certain temperature cooling programmer.

Step 6: Decide whether stop the annealing process according to the convergence criterion. If stop the annealing process, then turn to step 7. If not, turn to step 2.

Step 7: Output the current solution as the optimal solution.

Simulated annealing algorithm is an optimization algorithm which can effectively avoid local minimum and tend to the overall optimization, by the way of giving the search process a time-varying and eventually to zero probabilistic jumping property. But due to execute probability acceptance link, basic simulated annealing algorithm may miss the optimal solution encountered currently during the search process. In order to obtain the optimal results of the model, two stages are suggested in this paper. Solve the location and capacity in the first stage, and then solve the assignment decision of the construction waste and the recycling building materials based on stage 1.

CASE SIMULATIONS

Case definition: Because of the urban regeneration, it has the demand of the demolition of old buildings and the construction of new buildings in the urban built-up area. It will produce the construction waste when demolishing the old buildings, and call for construction materials when build the new buildings. Suppose there are five generation points of the construction waste and three recycling building materials demand points in the urban planning area, the specific coordinates are given in Table 2. Construction waste generation amount and the recycling building materials demanding amount in every point are also given in the Table 2.

Table 2: Coordinates and the amount.

	Name	Space coordinate	Generation amount/ demand amount
No.1	Generation point	(5,10)	500000
No.2	Generation point	(1,7)	850000
No.3	Generation point	(15,8)	1000000
No.4	Generation point	(7,17)	1500000
No.5	Generation point	(4,12)	1200000
No.1	Demand point	(13,18)	973500
No.2	Demand point	(18,11)	1010000
No.3	Demand point	(8,4)	3066500

Table 3: Parameters setting.

Parameter	Value	Parameter	Value
P	i	γ_j	50
ρ	0.7	β_j	20
w	120	Cycle index	500
$C_j max$	1800000	Annealing schedule	0.95
$C_j min$	1000000	Initial temperature	100

Considering the negative effects of the construction waste recycling center, which usually has the noise pollution and traffic disorder, the location distance and the capacity of the construction must be controlled to reduce the influence of ecological environment according to the urban planning requirements. In addition, the alternative areas of the construction waste recycling center are generally selected from the feasible location areas which are usually determined by GIS in the urban construction process, and then determine the locations and the capacity of construction. From the existing construction experience, if the location points are plethora, it will cause the phenomenon of waste. This paper, researches on the situation of a limited number of construction waste recycling center, and set the number as two.

Parameters setting and the result: The ratio of $x_{ij} = \frac{Q_{ij}}{Q_i}$ and $y_{jh} = \frac{Q_{jh}}{Q_j}$ values in [0,1]. In this paper, it is suggested that if the proportional value is more than 0.99 or less than 0.01, considering the problem of the organization and the operation, then short-cut process of $x_{ij} = \frac{Q_{ij}}{Q_i}$ and $y_{jh} = \frac{Q_{jh}}{Q_j}$ as 1or 0, and also control the ratio value in order to reduce the degree of search difficulty. The other parameters setting are given in Table 3.

By the model established in this paper and the solving method of the simulated annealing algorithm which is set for two stages, reorder the solutions obtained in the arithmetic which are non-inferior solutions for the reference. The result, which is processed by the planning empirical data are given in Table 4.

Table 4: Model results.

Location point/ Capacity	A[(10,9),1500000]		B[(4,10),1000000]
	A	B	
No.1 generation point	0.75/ 0.15	0.25/ 0.25	No.1 demand point
No.2 generation point	0/ 0.2	1.0/ 0.2	No.2 demand point
No.3 generation point	1.0/ 0.65	0/ 0.55	No.3 demand point
No.4 generation point	0.65/	0.35/	
No.5 generation point	0.45/	0.55/	

CONCLUSION

Construction waste is a serious problem in the urban regeneration, which may cause follow-up problems such as environment pollution and land occupation if the disposal of the construction waste is not handled properly. It is suggested that recycling use of the construction waste is a feasible way. In this paper, it proposes an uncertainty treatment method of the construction waste by building the construction waste resource center and establishes a strategy model, which includes construction waste resource center location, capacity design and the capacity arrangement. The solving method used in this paper can effectively solve the location, capacity and arrangement strategy based on a restricted number. The result shows that the strategy model and solving method are suitable for the problem of the construction waste problem.

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