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DEVELOPMENT OF A MUNICIPAL SOLID WASTE MANAGEMENT MODEL FROM THE PERSECTIVE UNDER UNCERTAINTY

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Abstract: In this study, an interval two-stage stochastic programming (ITSP) method is proposed for regional solid waste system management system under uncertainty. The ITSP approach can incorporate random events with punishment policies when the promised allowable waste loading is exceeded. An ITSP-based solid waste system management model is developed with an objective of minimizing economic cost in landfill and waste-to-energy (WTE) facility, which include operation, transportation, expansion costs and revenue. A case study in the city of Baotou, China is developed to manage the solid waste system. Three scenarios associated with different economic incentives are employed for analyzing the optimized solutions based on the preference of decision-makers. Under scenario without subsidy, the total system cost would be from 164.13 to 234.37 million yuan, however, due to the national policy subsidies, WTE would make profit and the total system cost would be negative (e.g. from -83.15 to -17.66 million yuan). The results indicated that a higher waste flow to landfill corresponds with a higher system cost, while more wastes transported to WTE facility lead to a lower economic cost. Financial subsidies for WTE facility could compensate the system loss and promote garbage resource utilization to some extent.

1. INTRODUCTION

Municipal solid waste management is an essential component in public health and environmental development, which has a great influence on regional construction and appearance of a city. With the rapid increasing population and decreasing land availability, a suitable solid waste management scheme is desired for decision maker. However, it is a very complicated system accompanied with many uncertainty parameters ranging from waste generation rate and expansion capacity to the cost of transportation and operation (Cai et al., 2009; Chen et al., 2016). Previously, a number of inexact mathematical programming models have been proposed for addressing various uncertainties in municipal solid waste management problems (Huang et al. 1993; Li et al., 2008; Nie et al., 2007; Dai, et al., 2011; Xu et al.,2009). Interval two-stage stochastic programming (ITSP) model could not only effectively deal with dynamic information with probability density functions, but also quantitatively analyze variety of policy scenarios when the promised targets are violated in decision-making process. ITSP is widely explored in many energy and environmental management problems (Huang and Loucks, 2000; Maqsood et al. 2003).

In this study, we first introduce the subsidy policy into this model with an objective of minimizing economic cost in landfill and waste-to-energy facility. Then we applied the ITSP-based municipal solid waste model into a real case study of Baotou city in China. Three scenarios are then assessed and compared based on different revenues under distinct subsidy incentives. The optimized solution will be useful for gaining insight into the municipal solid waste flow scheme under minimized economic cost objectives, and providing support for the related decisions in solid waste management system.

2. METHODOLOGY

In ITSP, decision variables are divided into two subsets: the first-stage variables must be determined before the realizations of random variables are known, and the second-stage variables that are determined after the realized values of the random variables are available (Lu et al., 2008; Birge and Louveaux, 2011). An ITSP-based solid waste management model can be expressed as follows:

Objective:

Minimize system costs: [1] $f=(a)+(b)+(c)-(d)$

(a) Total transportation cost: [2] $\sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{3}L_k X_{ijk}^{\pm} TR_{ijk}^{\pm} + \sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{3}\sum_{h=1}^{3} L_k EX_{ijkh}^{\pm} ETR_{ijk}^{\pm} P_{kh} + \sum_{k=1}^{3} L_k FT_k^{\pm} W_{2jkh}^{\pm}$

(b) Total operation cost: [3] $\sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{3}L_k X_{ijk}^{\pm} OP_{ik}^{\pm} + \sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{3}\sum_{h=1}^{3} L_k EX_{ijkh}^{\pm} EOP_{ik}^{\pm} P_{kh} + \sum_{k=1}^{3} L_k OP_{1k}^{\pm} W_{2jkh}^{\pm}$

(c) Total expansion cost: [4] $\sum_{i=1}^{2}\sum_{k=1}^{3} FLK_{ik}^{\pm} Y_{ik}^{\pm} CE_{ik}^{\pm}$

(d) Revenue from WTE: [5] $\sum_{j=1}^{4}\sum_{k=1}^{3}\sum_{h=1}^{3} L_k (X_{2jk}^{\pm} + EX_{2jkh}^{\pm} P_{kh}) RE$

Constraints:

(1) Facility capacity constraint

For WTE: [6] $\sum_{j=1}^{4}(X_{2jk}^{\pm} + EX_{2jkh}^{\pm}) \le TE_k^{\pm}; \forall k,h$, [7] $TE_k^{\pm} = TE_{k-1}^{\pm} + Y_{2k}^{\pm} CE_{2k}^{\pm}; k \ge 1$, [8] $TE_1^{\pm} = TE_0 + Y_{21}^{\pm} CE_{21}^{\pm}$

For Landfill: [9] $\sum_{j=1}^{4} L_k (X_{1jk}^{\pm} + EX_{1jkh}^{\pm} + W_{2jkh}^{\pm}) \le TL_k^{\pm}; \forall k,h$, [10] $TL_k^{\pm} = TL_{k-1}^{\pm} + Y_{1k}^{\pm} CE_{1k}^{\pm}; k \ge 1$, [11] $TL_1^{\pm} = TL_0 + Y_{11}^{\pm} CE_{11}^{\pm}$,

[12] $Y_{ik}^{\pm} = \begin{cases} 1, \text{ if expansion for facility i is undertaken in period k} \\ 0, \text{if otherwise} \end{cases}$

(2) Mass balance constraint

[13] $\sum_{i=1}^{2}(X_{ijk}^{\pm} + EX_{ijkh}^{\pm}) \ge WG_{jkh}^{\pm}, \forall j,k,h$, [14] $W_{2jkh}^{\pm} = (X_{2jk}^{\pm} + EX_{2jkh}^{\pm}) FE, \forall j,k,h$

where, *i* denotes waste disposal facility (*i* = 1 for landfill, and *i* = 2 for WTE); *j* is the district (*j* = 1for Kundulun, *j* = 2 for Qingshan, *j* = 3 for Jiuyuan, and *j* = 4 for Binhe); *k* represents the planning time period (*k* = 1 for 2020-2024, *k* = 2 for 2025-2029, and *k* = 3 for 2030-2034); *h* is the per capita waste generation rate level (*h* = 1 for low, *h* = 2 for medium, *h* = 3 for high level); *n* denotes the air pollutant from WTE (*n* = 1 for SO_x,

n = 2 for NO_x, n = 3 for PM, and n = 4 for dioxin); m represents the water pollutant from landfill leachate (m = 1 for COD, m = 2 for NH_3-N, and m = 3 for heavy metal); L_k is the length of period k (day); $X_{ijk}^{\pm}$ denotes pre-allocated waste loading from district j to facility i in period k (t/day); $TR_{ijk}^{\pm}$ is the transportation cost from district j to facility i during period k (¥/day); $EX_{ijkh}^{\pm}$ is the excess waste by which the waste generation allowance is exceeded from district j to facility i in period k under level h (t/day); $ETR_{ijk}^{\pm}$ represents the transportation cost for excess waste from district j to facility i during period k (¥/day); P_{kh} is the probability of waste generation in period k under level h; $FT_k^{\pm}$ denotes the transportation cost for WTE waste residue to landfill during period k (¥/day); $W_{2jkh}^{\pm}$ is the waste residue flow from WTE to landfill (t/day); $OP_{ik}^{\pm}$ denotes the operation cost of facility i in period k (¥/day); $EOP_{ik}^{\pm}$ is the operation cost for exceeded waste of facility i in period k (¥/day); $FLK_{ik}^{\pm}$ is expansion cost for facility i during period k (¥/t); $Y_{ik}^{\pm}$ denotes the binary variable for identifying whether or not to expand facility i in period k; $CE_{ik}^{\pm}$ represents the expansion capacity for facility i during period k (t); RE is the revenue from WTE during period k (¥/t); TE_0 and TL_0 are the existing capacity of WTE (t/day) and landfill (t); $TE_k^{\pm}$ and $TL_k^{\pm}$ denote the capacity of WTE (t/day) and landfill (t) in period k; $WG_{ikh}^{\pm}$ is the waste generation amount of district j in period k under level h (t/day); FE denotes the produced waste residue percentage of incoming waste mass in WTE.

3. CASE STUDY

Baotou City (40°15′～42°43′N, 109°15′～110°26′E), as the largest economy in Inner Mongolia Autonomous Region, China, includes four main municipal districts named as Kundulun (KDL), Qingshan (QS), Jiuyuan (JY) and Binhe (BH). There are an existing landfill disposal facility and a waste-to-energy (WTE) incineration plant for municipal solid waste treatment in Baotou. As population increase rapidly, the city is facing problem of secondary technology selection and capacity expansion. The total amount of municipal solid waste increased from 582.8 × 10^3 tonnes to 617.5 × 10^3 tonnes from 2000 to 2015 (Cai et al., 2000). According to National Development and Reform Commission on Improving the Policy for the Price of Electricity Generation from Waste Incineration, the general electricity generation capacity of waste garbage is 280 kWh/t, and the national subsidized power grid price is 0.65 ¥/kWh, which is much higher than the local power grid price 0.46 ¥/kWh. Thus, the obtained revenue through transforming waste to energy is 182.0 ¥/t (280 kWh/t *0.65 ¥/kWh=182.0 ¥/t) under subsidy policy. While without this financial incentive, it will drop down to 128.8 ¥/t. At the present stage, landfill is still the main way for regional solid waste treatment. Due to the limitation of available land area, municipal solid wastes treated by combustion will be subsidized by the government. Therefore, the problem we are facing is how to allocate the MSW flow to suitable disposal facilities with different subsidy scenarios under uncertainty. In order to reflect the dynamic variation of waste generation, a fifteen-years planning period from 2020-2034 is considered. In order to ensure the feasibility and practicability of general decision alternatives, three scenarios are designed to analysis the solution process. Scenario 1 (E0): the revenue is zero; scenario 2 (E1): the revenue is 128.8 ¥/t without subsidy; scenario 3 (E2): the revenue is 182.0 ¥/t with subsidy.

4. RESULTS AND DISCUSSION

Table 1 presents the solutions obtained from scenario 2 in the first period. The pre-allocated waste amount to landfill from four districts would be 300.0, 200.0, 30.0 and 40.0 t/day, respectively. In comparison, allowable waste flows to WTE from different districts would be 350.0, 250.0, 60.0, and 70.0 t/day, respectively. When considering excess flow waste, the optimized waste delivered to landfill under low and medium level from four districts remain the same, however, the total amount of waste delivered to WTE would increase to [350.0,429.6], [250.0,283.6] [60.0,70.5] and 70.0 t/day under low level and [566.9, 661.3], [374.6, 437.2], [89.3,102.3], and 70.0 t/day under medium level. The total waste flow is raising with the probability level. When the waste generation level is high, allowable waste flows to landfill from different districts would be [415.4,475.8], 400.0, [30.0,41.9], and 40.0 t/day, and the amounts to WTE is even larger. Under scenario without subsidy, the total system cost would be from 164.13 to 234.37 million yuan, however, due to the national policy subsidies, WTE would make profit and the total system cost would be negative (e.g. from -83.15 to -17.66 million yuan). In general, as the generation rate level increasing, the solid waste allocation to different facilities would be increased, and the waste amount allocated to WTE would be larger than that to landfill for different districts. It is mainly because that the huge revenue generated from waste-to-energy facility offsets the total system cost, leading to optimized waste diverted to WTE facility to get a lower economic cost objective. The results indicate that useful waste allocation pattern and expansion capacity can be obtained through the proposed approach for providing effective decision support for the decision-makers. However, more wastes flow to WTE incineration instead of landfill would cause potential air pollution from environmental aspect, which needs to be considered in our model for further discussion.

Table 1: Optimized solid waste flows under scenario 2 in the first period

Facility	District	Allowable waste load X_{ijk} (tonne)	Optimized waste flow X_{ijk}+EX_{ijk} (tonne)		
			L	M	H
Landfill	KDL	300.0	300.0	300.0	[415.4,475.8]
	QS	200.0	200.0	200.0	400.0
	JY	30.0	30.0	30.0	[30.0,41.9]
	BH	40.0	40.0	40.0	40.0
WTE	KDL	350.0	[350.0,429.6]	[566.9,661.3]	[686.7,700.0]
	QS	250.0	[250.0,283.6]	[374.6,437.2]	[294.1,379.4]
	JY	60.0	[60.0,70.5]	[89.3,102.3]	[114.2,120.0]
	BH	70.0	70.0	70.0	70.0

Reference

Birge, J. R., & Louveaux, F., 2011. Introduction to stochastic programming. Springer Science & Business Media.

Cai, Y. M., Wang, X. Y., 2000. The tenth five-year and up to 2015 planning of environmental protection of solid wastes in Baotou. **12**(4), 12-15. (In Chinese)

Cai, Y. P., Huang, G. H., Lu, H. W., Yang, Z. F., & Tan, Q., 2009. I-VFRP: An interval-valued fuzzy robust programming approach for municipal waste-management planning under uncertainty. *Engineering Optimization*, **41**(5), 399-418.

Chen, X., Huang, G., Zhu, H., Suo, M., & Dong, C., 2016. Inexact Inventory Theory–Based Waste Management Planning Model for the City of Xiamen, China. *Journal of Environmental Engineering*, **142**(5), 04016013.

Dai, C., Li, Y. P., & Huang, G. H., 2011. A two-stage support-vector-regression optimization model for municipal solid waste management–a case study of Beijing, China. *Journal of environmental management,* **92**(12), 3023-3037.

Huang, G. H., Baetz, B. W., & Patry, G. G., 1993. A grey fuzzy linear programming approach for municipal solid waste management planning under uncertainty. *Civil Engineering Systems*, **10**(2), 123-146.

Huang, G. H., & Loucks, D. P., 2000. An inexact two-stage stochastic programming model for water resources management under uncertainty. *Civil Engineering Systems,* **17**(2), 95-118.

Li, Y. P., Huang, G. H., & Xiao, H. N., 2008. Municipal solid waste management under uncertainty: an interval-fuzzy two-stage stochastic programming approach. *Journal of Environmental Informatics,* **12**(2).

Lu, H. W., Huang, G. H., Zeng, G. M., Maqsood, I., & He, L., 2008. An inexact two-stage fuzzy-stochastic programming model for water resources management. *Water Resources Management,* **22**(8), 991-1016.

Maqsood, I., & Huang, G. H., 2003. A two-stage interval-stochastic programming model for waste management under uncertainty. *Journal of the Air & Waste Management Association,* **53**(5), 540-552.

Nie, X. H., Huang, G. H., Li, Y. P., & Liu, L. I. F. R. P., 2007. IFRP: A hybrid interval-parameter fuzzy robust programming approach for waste management planning under uncertainty. *Journal of environmental management,* **84**(1), 1-11.

Xu, Y., Huang, G. H., Qin, X. S., & Huang, Y., 2009. SRFILP: A stochastic robust fuzzy interval linear programming model for municipal solid waste management under uncertainty. *Journal of Environmental Informatics,* **14**(2).