Academia Journal of Scientific Research 6(9): 000-000, September 2018
DOI: 10.15413/ajsr.2018.0207
ISSN 2315-7712

Academia Publishing

CrossMark

Research Paper

A newly merged metropolis to develop MSW management systems using mathematical programming method

Accepted 26th September, 2018

Shu-Lung Kuo[1] and Ching-Lin Ho[2]*

[1] Kelee Environmental Consultant Corporation, Taiwan

[2] *Correspondent author.
Department of Technology Managenent, Open University of Kaohsiung, Taiwan
E-mail:hcl6005@ouk.edu.tw

ABSTRACT

Kaohsiung City and County, the two administrative regions with entirely different administrative status, resources, and area of development were merged into one administrative entity on 25, Dec. 2010. A new top-level plan for managing the municipal solid wastes (MSW) has to be implemented in time in order to provide services of equal quality and environmental conditions to all residents without delay. The authors initiate a new plan at the top level to provide a platform for planning sub-level soild waste collection and disposal systems. To address the issue, this study used an new methodology of urban planning and (0,1) mixed integer programming model within the systems to be built and maintained/operated at minimum system cost. Hence, the model could reflect the actual solid waste complexity in the newly merged region and can provide valuable information for top-down planning of future sub-systems projects. In addition, the case study focuses on the MSW planning after the consolidation of two districts. The objective is to construct and propose a new mathematical methodology for the reference of readers in related fields.

Key words: Mathematical programming, intermediate treatment facilities, optimization, MSW, incineration plant, chaos.

INTRODUCTION

Kaohsiung City, which was originally a municipality subordinate to the Executive Yuan of Taiwan government and the second largest city in Taiwan, was merged with its neighboring Kaohsiung County to form a new Kaohsiung Municipality, on 25 Dec. 2010. The two administrative regions are entirely different administrative status, resources and area of development.

After the amalgamation, the city and the county became one identity, such that the residents in the entire region should enjoy the same level of services, and the same demand of environmental conditions. The demand and expectation of all residents should be equally satisfied.

Therefore, the development of a superior plan (the top-level plan) that forms the basis for new solid waste collection, treatment, and disposal system is increasingly urgent for the new government.

Based on the superior plan, detailed design of the solid waste collection machinery and manpower, collection routes, installation of collection point, and solid waste collection time at each point can proceed (Shane et al., 2013).

Numerous researchers have conducted several studies on the MSW optimization since 1980s. Mathematical models have been developed and implemented to establish long-term programming models for planning solid waste management (Minciardi et al., 2002; Cai et al., 2007; Li and Huang, 2009; Tan et al., 2010) and for supporting decisions on short-term waste management operation (Lu et al., 2006; Li et al., 2009; Chung 2010; Wang et al., 2012; Senthilkumar and Varghese, 2013).

In the MSW management, uncertainties exist in related costs, impact factors and objectives, which are presented as fuzzy, probability and/or interval formats. Such uncertainties can affect the related optimization processes and the generated decision schemes (Yeomans et al., 2003; Alves et al., 2009; Lin et al., 2010; Li and Huang, et al., 2012). Consequently, various method dealing with uncertainties have been developed for the planning of MSW management systems (Chang et al., 2005; Chang and Davila, 2007; Moeinaddini et al., 2010).

In the field of urban planning, it is stipulated that the superior plan including uncertainty in the MSW management at the top level is not appropriate (Madanipour, 2006; Levy, 2010). If uncertainties are included, they will cause chaos at the next subordinate level of the detailed MSW planning (Lee and Kim, 2000; Vincent et al., 2002; Lin et al., 2010; Li and Huang, 2012).

In addition, the superior plan must assure the principle of certainty, and hence, problems with uncertainty will not be considered in this research.

Besides, treatment systems of municipal solid wastes in other developed countries are equipped with intermediate treatment facilities of high-quality. On the other hand, there are only incinerators but intermediate treatment facilities in metropolitan areas of Taiwan. As a result, in order to make a complete treatment system of municipal solid wastes in Taiwan, which is necessary for metropolitan areas, an intermediate treatment facility needs to be equipped in line with the current MSW management plan. This allows a (0,1) mixed integer programming model to be developed to manage the system.

The major purpose of this research was to provide a superior plan model and solutions that can be referenced by the new municipal government for planning the subsequent detailed solid waste system.

METHODOLOGY

Brief remarks

Most waste disposal systems perform three basic operations: collection, intermediate processing and final disposal. The waste generation might be viewed as part of the disposal system because changes in consumer habits can significantly alter the nature of materials requiring disposal. For the purpose of modeling the system as a whole, the amount and the character of the waste stream will be taken as given parameters in this study.

(0.1) Mixed integer programming of MSW system

The authors developed a (0.1) mixed integer programming model to illustrate the system situation. This is given as:

Minimize:

$$\sum_{i=1}^{m} F_i y_i + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}^{*} X_{ij}^{*} + \sum_{i=1}^{m}\sum_{k=1}^{p} C_{ki}^{**} X_{ki}^{**} \qquad (1)$$

Subject to the constraints:

$$\sum_{i=1}^{m} X_{ki}^{**} \geq S_k \qquad k=1,2,......,p \qquad (2)$$

$$\sum_{j=1}^{n} X_{ij}^{*} = \alpha_i \sum_{k=1}^{p} X_{ki}^{**} \qquad i=1,2,......,m \qquad (3)$$

$$\sum_{k=1}^{p} X_{ki}^{**} \leq Q_i y_i \qquad i-1,2,......,m \qquad (4)$$

$$D_j^{u} \geq \sum_{i=1}^{m} X_{ij}^{*} \geq D_j^{l} \qquad j=1,2,......,n \qquad (5)$$

$$\sum_{k=1}^{p} X_{ki}^{**} \geq A_i^{l} \qquad i=1,2,......,4 \qquad (6)$$

$$X_{ij}^{*},\ X_{ki}^{**} \geq 0 \quad \text{are non-negative integers} \qquad (7)$$

$$y_i = 1 \qquad i=1,2,.......,4 \qquad (8)$$

$$y_i = \begin{cases} 1; & \text{if the intermidate facility is built or} \\ 0; & \text{otherwise} \end{cases} \qquad (9)$$

Where:

X_{ij}^{*} = flow of material from facility i to sink j

X_{ki}^{**} = flow of material from source k to intermediate point i

$C_{ij}^{*} = C_{ij} + r_j$ = unit cost associated with a transfer of material from facility i to sink j (dollars per unit)

C_{ij} = unit shipping cost facility i to sink j (dollars per unit)

r_j = unit variable cost associated with using sink j(dollars per unit)

$C_{ki}^{**} = C_{ki}^{'} + t_k + v_i$ = unit cost associated with transfer of material from source k to facility i (dollars per unit)

$C_{ki}^{'}$ = unit shipping cost from source k to facility i (dollars per unit)

t_k = unit variable cost associated with using source k (dollars per unit)

v_i = unit variable cost associated with using facility i (dollars per unit)

F_i = fixed charge for establishing facility i (dollars)

S_k = amount supplied at source k

D_j^{u} = upper bound on amount demanded at sink j

D_j^{l} = lower bound on amount demanded at sink j

Q_i = capacity of the i'th facility

A_i^l =lower bound of incinerator operation (minimum required amount of waste for incinerator.)

$\begin{cases} i = 1,2,\ldots\ldots,m \\ m = \text{Number of proposed intermediate facility sites} \end{cases}$

$\begin{cases} j = 1,2,\ldots\ldots,n \\ n = \text{Number of demand areas, (final disposal sites), (} \end{cases}$

$\begin{cases} k = 1,2,\ldots\ldots,n \\ p = \text{Number of supply point (waste generation points} \end{cases}$

α : reduction ratio of the incineration of waste

Model description

1). The objective function is to determine which facilities should be built and which sources and sinks each facility serves, so that the total cost of facilities and tran-shipment is minimized. Where $\sum_{i=1}^{m} F_i y_i$ represents the fixed costs for *i*, $\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}^{*} X_{ij}^{*}$ represents the shipment costs from *i* to *j*, and operation cost in *j*, and $\sum_{i=1}^{m}\sum_{k=1}^{p} C_{ki}^{**} X_{ki}^{**}$ represents the shipping costs from *k* to *i*.
2). Inequality (2) expresses the requirement that flow from the source can not exceed the supply of material there.
3). Equation (3) states the conservation of flow requirement that the flow entering the i-th facility must be equal to the flow leaving it.
4). In Equation (4), the fixed charge nature of facility location is expressed. If the *i*-th facility does not exist, then $y_i = 0$ and no flow may take place through it.
5). Equation (5) specifies that flow to sink *j* must be between the upper and lower bound on the capacity of the sink.
6). Equation (6) specifies that flow from source *k* to incineration plant *i* must be greater than the lower bound of incineration.
7). Equation (8) expresses that in the present case study, there existed 4 incinerators already. And just began to operate for couple of years.

CASE STUDY

The amount of waste generation

Taiwan is experiencing a period of zero population growth in the recent years, and waste resources recycling activities have always been successful. As such, the amount of waste generation should be fixed at a constant level in this research.

Overview of the studied system

Incineration plant

There are two incineration plants in the original Kaohsiung City, that is, Kaohsiung Central Incineration Plant and Kaohsiung Southern Incineration Plant. The central plant, which is capable of treating 900 T/day of solid waste, consists of 3 sets of 300 T/day incinerators, whereas the southern plant is capable of treating 1800 T/day of solid waste with four 450 T/day incinerators. The original Kaohsiung County has 2 incineration plants: Renwu Incineration Plant and Kangshan Incineration Plant. Each plant has a total treatment capacity of 1350 T/day with 3 sets of 450 T/day incinerators. The expected design lives of these 4 incineration plants are all 30 years. They were put into operation in 1999 and 2000 and as such, have not reached the limit of their designed useful lives. The policy promulgated by Taiwan Environmental Protection Administration (Taiwan EPA) stipulates that no more incineration plant can be constructed in Taiwan (Taiwan EPA, 2003). Hence, these existing incineration plants will not have the problem of site selection, and the incineration plant construction cost will not be considered in this research.

Sanitary landfill site

There are 10 sanitary landfill sites in the original Kaohsiung County. All of them have not reached the designed life limit. Hence, the problem of sitting or expanding sanitary landfill is not addressed in this research.

Intermediate treatment facility

A typical intermediate treatment facility consists of incineration plant, resource recovery station, solid waste transfer station, solid waste compression station, and others (Chang et al., 2005; Chang et al., 2012). Except incineration plant, all other components have not been constructed. Based on the current solid waste collection practice, and the objective for seeking the minimum solid waste transportation cost, the policy maker of Kaohsiung municipal government agrees that only the installation of solid waste transfer posts at Neimen Township, Hunei Township, Qishan Township, Luzhu Township, Yanchao township and Nanzih Distinct will be included in the future planning. Therefore, the setting up of these transfer posts to handle 500 T/day of solid waste are carried out according to the (0,1) mixed integer programming model solutions.

Figure 1 shows the map of the New Kaohsiung Municipality and location of existing and potential facilities.

Figure 1: Map of the New Kaohsiung Municipality and location of exisiting and postential facilities.

Computer aid

The (0,1) mixed integer programming model could be solved using various available software programs, including Excel, Lingo, Metlab, Ilog Cplex, and Gams (He et al., 2009). However, Lingo was chosen because it can be used conveniently, practicality, and quickly to solve non-linear problems (Lingo, 2008).

RESULTS AND DISCUSSION

Selection of the potential facility

Table 1 expresses the results of the intermediate facility built or not.

The optimal solutions of decision variables

Table 2 shows the optimal solution of the decision variables from sources to intermediate facility. While Table 3 shows the optimal solution of the decision variables from intermediate facility to sink.

CONCLUSION

1). The authors induced the theory of contemporary urban planning to setting the developed model as a superior plan (the top-level plan). The MSW management model should be deterministic without uncertainty consideration, so that the sub-level plan (optimal MSW collection route, optimal collection points, optimal dispatch of manpower,..., etc) can be proceeded smoothly without the possibility of running into chaotic situations. But in the sub-level MSW plan uncertainties exist in related costs, impact factors and objectives.

2). The authors suppose that other objectives just like social and environmental objectives are also very important and should also be considered in their future research, especially presented as a multi-objective programming model.

3). There are several additional constraints or side conditions that might be of interest in the above formulation. The main purpose of this study is to develop a quick and easy methodology, so that the mixed integer programming can be provided to the government.

4). The optimal solution of this study has been implemented by the new Kaohsiung municipal government on July 1, 2011. It could be proven that the cost incurred by

Table 1: Expresses the results of the intermediate facility is built or not.

Yi (intermediate facility)	1 Facility is built or 0 Otherwise
Y1	1
Y2	1
Y3	1
Y4	1
Y5	0
Y6	0
Y7	1
Y8	0
Y9	0
Y10	0

Table 2: The optimal solution of the decision variables from sources to intermediate facility.

X_{ij}^{**} (k i)	Metric tons	X_{ij}^{**} (k i)	Metric tons
X_{ij}^{**} (8 1)	317000	X_{ij}^{**} (17 3)	137182
X_{ij}^{**} (9 1)	837031	X_{ij}^{**} (18 3)	174442
X_{ij}^{**} (10 1)	124591	X_{ij}^{**} (4 4)	309087
X_{ij}^{**} (11 1)	639489	X_{ij}^{**} (19 4)	404220
X_{ij}^{**} (12 1)	1415422	X_{ij}^{**} (20 4)	151675
X_{ij}^{**} (13 1)	296079	X_{ij}^{**} (24 4)	226608
X_{ij}^{**} (14 1)	456758	X_{ij}^{**} (25 4	119343
X_{ij}^{**} (1 2)	116902	X_{ij}^{**} (26 4)	132284
X_{ij}^{**} (2 2)	527948	X_{ij}^{**} (27 4)	86384
X_{ij}^{**} (3 2)	335313	X_{ij}^{**} (28 4)	58958
X_{ij}^{**} (5 2)	1484793	X_{ij}^{**} (29 4)	153941
X_{ij}^{**} (6 2)	236291	X_{ij}^{**} (21 7)	129965
X_{ij}^{**} (7 2)	123769	X_{ij}^{**} (22 7	35040
X_{ij}^{**} (8 2)	459984	X_{ij}^{**} (23 7)	128321
X_{ij}^{**} (3 3)	453069	X_{ij}^{**} (30 7)	169907
X_{ij}^{**} (4 3)	403607	X_{ij}^{**} (31 7)	182277
X_{ij}^{**} (15 3)	185685	X_{ij}^{**} (32 7)	46630
X_{ij}^{**} (16 3)	288515	X_{ij}^{**} (33 7)	67744

Table 3: The optimal solution of the decision variables from intermediate facility to sink.

X^*_{ij} (k i)	Metric Tons	X^*_{ij} (k i)	Metric Tons
X^*_{ij} (1 1)	266578	X^*_{ij} (3 5)	411800
X^*_{ij} (1 2)	959333	X^*_{ij} (4 5)	264704
X^*_{ij} (2 2)	886450	X^*_{ij} (4 6)	51464
X^*_{ij} (2 3)	99050	X^*_{ij} (4 7)	12732
X^*_{ij} (3 3)	80950	X^*_{ij} (4 8)	130000
X^*_{ij} (4 4)	33850	X^*_{ij} (7 9)	759884

implementing this plan will be significantly lower than that incurred by the original arrangement of waste management. And according to the early feed back from the city government, the authors' plan has saved about 20~30% of cost as compared with the cost before the combination.

5). Sensitivity analysis is the process of investigating the dependence of an optimal solution to change in the way a problem is formulated. Performing a sensitivity analysis is a key part of the design process, equal in importance to the optimization process itself. However, due to the time and budget limitation of the grant, it was difficult for the authors to add a comprehensive sensitivity analysis into the current article.

6). The case study focuses on the MSW planning after the consolidation of two districts. The objective is to construct and propose a new mathematical methodology for the reference of readers in related fields.

REFERENCES

Alves MC, Lima BS, Evsukoff AG, Vieira IN (2009). Developing a fuzzy decision support system to determine the location of a landfill site. Waste Manag. Res. 27(7): 641-651.

Cai YP, Huang GH, Nie XH, Li YP, Tan Q (2007). Municipal soild waste management under uncertainty: a mixed interval parameter fuzzy-stochastic robust pogramming approach. Environ. Eng. Sci. 24(3): 338-352.

Chang NB, Davila E (2007). Minmax regret optimization analysis for a regional solid waste management system. Waste Manag. 27(6): 820-832.

Chang NB, Davila E, Dyson B, Brown R (2005). Optimal design for sustainable development of a recycling facility in a fast-growing urban setting. Waste Manag. 25(8): 833-846.

Chang YJ, Chu CW, Lin MD (2012). An economic evaluation and assessment of environmental impact of the municipal solid waste management system for Taichung city in Taiwan. J. Air Waste Manag. Assoc. 62(5): 527-540.

Chung SS (2010). Projection of trends in solid waste generation: the case of domestic in Hong Kong special administrative region. Environ. Eng. Sci. 27(1): 13-20.

He L, Huang GH, Zeng GM, Lu HW (2009). Identifying optimal regional solid waste management strategies through an inexact iInteger programming model containing infinite objectives and constraints.Waste Manag. 29(1): 21-31.

Lee JW, Kim SH (2000). Using analytic network process and goal programming for independent information system project. Comput. Oper. Res. 27(4): 367-382.

Levy JM (2010). Contemporary urban planning, 9th edition. Longman Publisher Group, New York, USA.

Li YP, Huang GH (2009). Inexact minimax regret integer programming for long-term planning of municipal solid waste management-part A: Methodology development. Environ. Eng. Sci. 26(1): 209-218.

Li YP, Huang GH (2012). Modeling municipal solid waste management system under uncertainty. J. Air Waste Manag. Assoc. 60(4): 439-453.

Li YP, Huang GH, Yang ZF, Nie SL (2009). IFTCIP: An integrated optimization model for environmental management under uncertainty. Environ. Model. Assess. 14(3): 315-332.

Lin C, Wu EMY, Lee CN, Kuo SL (2010). Applying multivariate statistical factor analyses on selecting an optimal method for recycling of food wastes. Environ. Eng. Sci. 28(5): 349-356.

Lin MC, Wu EMY, Teng J, Huang WC (2010). Cooperation-competition model of transportation construction. J. Mar. Sci.Technol. 18(6): 915-923.

Lingo (Linguistic Grammars Online, LINGO), version 10.0, (2008). Lindo systems inc. North Dayton Street Chicago, Illinois, USA, Purchased from Bocky Tech. Inc., Taiwan.

Lu LT, Yu YH, Shang NC, Yang YM, Ma HW, Chen LJ, Hsiao TY (2006). Material flow analysis of cadmium applied to review MSW treatment in Taiwan. J. Chinese Institute Eng. 29(5): 769-775.

Madanipour A (2006). Roles and challenge of urban design. J. Urban Design 11(2): 173-193.

Minciardi R, Paolucci M, Robba M, Sacile R (2002). A multi-objective approach for solid waste management," *Proceedings of the 1st Biennial Meeting of the* International Environmental Modelling and Software Society *(iEMSs)*. 3(3): 205-210.

Moeinaddini M, Khorasani N, Danehkar A, Darvishsefat AD, Zienalyan M (2010). Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). Waste Manag. 30(5): 912-920.

Senthilkumar V, Varghese K (2013). Case study-based testing of design interface management system. J. Manag. Eng. 29(3): 279-288.

Shane J, Bogus S, Molenaar K (2013). Municipal water/wastewater project delivery performance comparison. J. Manag. Eng. 29(3): 251-258.

Taiwan EPA (2003). Design criteria for incineration plant in Taiwan-2003. Yearly Report, Taipei, Taiwan.

Tan Q, Huang GH, Cai YP (2010). A superiority-inferiority-based inexact fuzzy stochastic programming approach for solid waste management under uncertainty. Environ. Model. Assess. 15(5): 381-396.
Vincent LSK, Wong BK, Cheung WM (2002). Group decision making in multiple criteria environment: A case using the AHP in software selection. Eur. J. Oper. Res. 137(1): 134-144.
Wang CC, Lin MD, Lin CF (2012). Factors influencing regional municipal solid waste management strategies. J. Air Waste Manag. Assoc. 58(7): 957-964.
Yeomans JS, Huang GH, Yoogaingam R. (2003). Combining simulation with evolutionary algorithms for oOptimal planning in the regional municipality of Hamilton-Wentworth. J. Environ. Inform. 2(1): 11-30.