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Optimization of long-term performance of municipal solid waste management system: A bi-objective mathematical model

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Abstract
Management of municipal solid waste has becoming an extremely important topic for any urban authorities in recent years due to the rapidly increasing solid waste quantity and potential environmental pollution. In this paper, a bi-objective dynamic linear programming model is developed for decision making and supporting in the long-term operation of municipal solid waste management system. The proposed mathematical model simultaneously accounts both economic efficiency and environmental pollution of municipal solid waste management system over several time periods, and the optimal tradeoff over the entire studied time horizon is the focus of this model. The application of the proposed model is also presented in this paper, and the computational result and analysis illustrate a deep insight of this model.

Keywords: Waste management; Municipal solid waste; Multi-criteria analysis; Dynamic programming; Environmental pollution.

1. Introduction

Solid waste management has becoming a challenging task for any municipal authorities due to rapidly increasing waste amount, increasing concern for environmental pollution, more complex waste composition, as well as limited capacity for waste treatment and disposal [1]. In order to operate municipal solid waste management system in a cost efficient and sustainable manner, the decision-makers should look at the "overall picture" from long-term perspectives. On one hand, the system operating cost should be minimized so that the increasing amount of solid waste can be efficiently and effectively treated and disposed, and this is especially important for developing countries where the fast increase of solid waste due to the rapid urbanization and industrialization has become a burden for both municipalities' infrastructure and the community [2]. On the other hand, the concern of environmental pollution and risk (e.g. contamination of surface water and ground water from landfill, air pollution from incineration, etc.) from the public have been significantly increased in recent years, furthermore, the emission of greenhouse gases from the treatment and disposal of increase quantity of municipal solid waste is also accused as one of the primary contributors to global warming and climate change [3, 4]. However, the cost objective and environmental pollution/risk objective are conflict with one another, the optimal scenario for one objective usually lead to a bad solution for the other [5]. Therefore, the optimal balance between economic efficiency and environmental pollution is of significance in determining the long-term performance of municipal solid waste management system.

Previously, a large number of studies focused on the optimization of municipal solid waste management system [6]. Son [2] proposes a computational model for vehicle routing problem of waste collection, and the model is resolved through combining chaotic particle swarm optimization with global information system. The waste collection problem is also focused by Ghiani et al. [7] who develop a two-stage location model. The first step is to determine the number and locations of waste collection bins in a residential area, and the second step is to decide the service zone of each waste collection bin and optimal route of waste collection vehicles. Eiselt and Marianov [8] report a bi-objective optimization model for determining the most appropriate location of waste treatment and disposal facilities, and the tradeoff between economic efficiency and environmental issue is the focus of this location model. Badran and El-Haggar [9] propose a mixed integer programming model for determining the optimal configuration of a multi-echelon municipal waste management system through minimizing the overall cost, and a real-world case at Port Said, Egypt, is also presented in the study. Zhang and Huang [10] develop a single objective model in order to mitigate greenhouse gas emissions associated with municipal solid waste management system, and fuzzy possibilistic integer programming is employed for dealing with uncertain parameters. Alcada-Almeida et al. [11] investigate a multi criteria approach for locating incineration plant in Portugal. The tradeoff among overall system cost, total impact, maximum average impact and impact to individuals is optimized in this study, and the overall system cost is comprised of annualized investment and processing cost. A multi-objective approach for determining the optimal configuration of waste management system is developed by Galante et al. [12]. In order to optimize the tradeoff of total cost and environmental impact, a combination of mathematical tools including fuzzy multi-objective programming, weighed sum as well as goal programming is applied in this study. Dai et al. [13] formulate a mixed integer linear programming model with interval parameters for the optimization of municipal solid waste management system, and a support-vector-regression approach is developed as well. Mavrotas et al. [14] propose a bi-objective integrated optimization model for simultaneously minimizing the overall system cost and greenhouse gas emissions related to the transportation and treatment of municipal solid waste. A generic cost-minimization formula for the network design and planning of municipal solid waste management system is investigated by Eiselt and Marianov [15], and the location selection of landfill and transfer station is especially emphasized in this study.

Generally, the location problem related to municipal solid waste management system has played a predominant role in previous studies, and different mathematical tools such as linear programming, nonlinear programming, goal programming, mixed integer programming, multi-objective programming, etc., have been extensively applied for formulating and resolving the location problems of municipal solid waste management system. However, the scope of previous studies is limited to the network design, expansion and development of municipal solid waste management system, and the optimal and most sustainable operation planning of existing waste management systems is rarely mentioned. In this paper, different from previous literature, the location problem of waste treatment and disposal facilities is not taken into consideration, but the optimal operation planning of municipal solid waste management system over a set of continuous time periods is focused, and a bi-objective dynamic optimization model is developed to determine the optimal operation plan of the municipal solid waste management system within the studied time horizon. Moreover, the solution method and numerical experimentation of this model are also presented latter in this paper, and the computational result and analysis illustrate a deep insight of this model.

2. The model

Based upon the reverse waste supply chain network developed by Zhang et al. [16], municipal solid waste management system is constituted by three levels of facilities, namely local waste collection center, regional distribution center as well as treatment and disposal facility, and Figure 1 illustrates a simplified framework of municipal solid waste management system. Local waste collection can be considered as the initial step of municipal solid waste management system, and the locally collected waste will then be sent to regional distribution center at which separation and pre-treatment of solid waste are performed in order to provide appropriate “input resources” to the subsequent waste treatment and disposal plants. Finally, different types of municipal solid waste will be treated or properly disposed through corresponding treatment methods i.e. recycling, incineration, composting, mechanical biological treatment, landfill, etc.

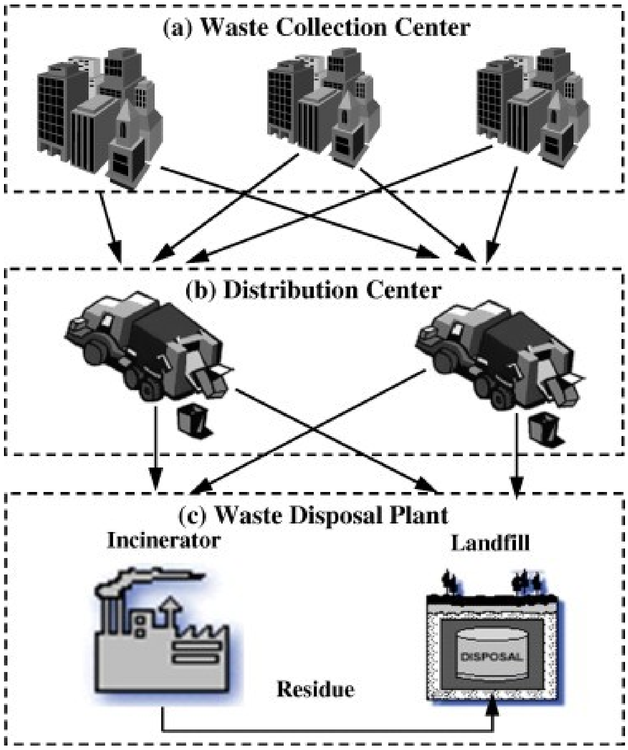

Figure 1. Municipal solid waste management system [16]

2.1 Objective function

The overall cost of municipal solid waste management system within the studied time horizon is expressed in Eq. (1). The first four parts in this equation represent the annualized investment and flexible operating cost of waste collection, distribution, treatment and disposal, respectively. The other three parts formulate the inter-facility transportation cost from waste collection center to distribution center, from distribution center to treatment plant, and from distribution center to landfill. The flexible facility operating cost and inter-facility transportation cost are linearly associated with the quantity of solid waste.

$$\begin{aligned}\text{Min } cost = &\sum_{1}^{s}\sum_{1}^{c}(AI_{c(s)} + WCC_{c(s)}QT_{c(s)}) + \sum_{1}^{s}\sum_{1}^{dt}(AI_{dt(s)} + WDtC_{dt(s)}QT_{dt(s)}) \\ &+ \sum_{1}^{s}\sum_{1}^{t}(AI_{t(s)} + WTC_{t(s)}QT_{t(s)}) + \sum_{1}^{s}\sum_{1}^{d}(AI_{d(s)} + WDC_{d(s)}QT_{d(s)}) \\ &+ \sum_{1}^{s}\sum_{1}^{c}\sum_{1}^{dt} WTpC_{c/dt(s)}QTp_{c/dt(s)} + \sum_{1}^{s}\sum_{1}^{dt}\sum_{1}^{t} WTpC_{dt/t(s)}QTp_{dt/t(s)} \\ &+ \sum_{1}^{s}\sum_{1}^{dt}\sum_{1}^{d} WTpC_{dt/d(s)}QTp_{dt/d(s)}\end{aligned} \quad (1)$$

The environmental pollution of municipal solid waste management system is formulated in Eq. (2). The environmental pollution indicator illustrates the pollution level and potential risk of each plant. The environmental pollution related to waste distribution, treatment and disposal linearly increases with the increase of solid waste quantity, while it linearly decreases with the increase of the distance between population center and waste management facility. It is noteworthy that the distance between existing plants and communities is fixed and not changes with time, so the periodic adjustment is not applied for this parameter, however, the environmental pollution indicator may be changed within the studied period due to technological upgrade or other developments. Besides, the population of each affected area is introduced to pollution-minimization objective as an important adjustment factor in order to minimize the environmental pollution to the most populated communities.

$$\text{Min } pollution = \sum_{1}^{s}\sum_{1}^{af} POL_{af(s)} \left(\sum_{1}^{dt} \frac{EP_{dt(s)}QT_{dt(s)}}{DS_{dt/af}} + \sum_{1}^{t} \frac{EP_{t(s)}QT_{t(s)}}{DS_{t/af}} + \sum_{1}^{d} \frac{EP_{d(s)}QT_{d(s)}}{DS_{dt/af}}\right) \quad (2)$$

It is prerequisite that all the waste collected at each defined time period is totally treated or disposed, so the cost and environmental pollution related to waste storage at each period is not taken into consideration.

2.2 Composite objective function

The model is formulated through multi-period linear programming for simultaneously minimizing the overall system cost and environmental pollution of municipal solid waste management system. In order to combine cost-minimization and pollution-minimization objective, the challenge brought by different measure of units of those two objective functions must be first resolved. In this paper, a weighted sum utility method developed from Nema and Gupta [17] is introduced in Eq. (3), and similar method for combining multi-objective functions with different units is also provided by Hu et al. [18] and Yu et al. [19]. The optimal solution of cost-minimization and pollution-minimization can be first found out through solving the single objective linear function, and the unit of $\frac{Cost\ objective}{Min\ cost}$ and $\frac{Pollution\ \ objective}{Min\ pollution}$ can then be eliminated. In Eq. (3), ∂_C and ∂_p indicate the importance of relevant objective function, and they follow the relation $\partial_p = 1 - \partial_C$.

$$\text{Min } objective = \partial_C \frac{Cost\ objective}{Min\ cost} + \partial_p \frac{Pollution\ objective}{Min\ pollution} \quad (3)$$

2.3 Constraints

The waste amount collected at each community by local collection center cannot be more than the maximum collecting and storage capacity in each period (Eq. (4)). For waste collection center, the entire input waste amount are totally processed, and it also equals to the summation of waste transported to all distribution centers in each period (Eq. (5)). Those two constraints are conflict with each other when the waste amount generated in one community exceed the capacity of local waste collection center, and expansion of limited waste collection capacity must be planned under such condition so that the result solved by this model is meaningful.

$$QT_{c(s)} \le MAX_{c(s)}, \text{For } 1, \dots, c, 1, \dots, s \quad (4)$$

$$\sum_{1}^{dt} QTp_{c/dt(s)} = QT_{c(s)} = SW_{c(s)}, \text{For } 1, \dots, c, 1, \dots, s \quad (5)$$

For each waste distribution center in each period, the maximum capacity and minimum quantity constraints must be fulfilled (Eqs. (6) and (7)). For waste distribution center, treatment plant as well as disposal facility, the minimum waste processing amount is required so as to maintain the economic efficiency for opening and operating the waste management facilities. If the utilization of waste management facility is very low, the annualized investment will constitute a significant share in the overall system operating cost, and the spare capacity will become a big economic burden for the waste management companies. Besides, the summation of input waste from local collection centers equal to the summation of waste transported to the treatment plants and disposal facilities at each regional distribution center in each period (Eq. (8)).

$$QT_{dt(s)} \le MAX_{dt(s)}, \text{For } 1, \dots, dt, 1, \dots, s \quad (6)$$

$$QT_{dt(s)} \geq MIN_{dt(s)}, \text{For } 1, \ldots, dt, 1, \ldots, s \tag{7}$$

$$\sum_{1}^{c} QTp_{c/dt(s)} = QT_{dt(s)} = (\sum_{1}^{t} QTp_{dt/t(s)} + \sum_{1}^{d} QTp_{dt/d(s)}), \text{For } 1, \ldots, dt, 1, \ldots, s \tag{8}$$

Similarly, the maximum processing capacity and minimum required waste amount at treatment plant and disposal facility in each period are restricted by Eqs. (9), (10), (12) and (13), respectively. Eqs. (11) and (14) regulate the input waste amount equals to the waste quantity processed at treatment plant and disposal facility in each period. In addition, the numerical values of all the parameters and decision variables in this bi-objective multi-period optimization model for municipal solid waste management system are positive.

$$QT_{t(s)} \leq MAX_{t(s)}, \text{For } 1, \ldots, t, 1, \ldots, s \tag{9}$$

$$QT_{t(s)} \geq MIN_{t(s)}, \text{For } 1, \ldots, t, 1, \ldots, s \tag{10}$$

$$\sum_{1}^{dt} QTp_{dt/t(s)} = QT_{dt(s)}, \text{For } 1, \ldots, t, 1, \ldots, s \tag{11}$$

$$QT_{d(s)} \leq MAX_{d(s)}, \text{For } 1, \ldots, d, 1, \ldots, s \tag{12}$$

$$QT_{d(s)} \geq MIN_{d(s)}, \text{For } 1, \ldots, dt, 1, \ldots, s \tag{13}$$

$$\sum_{1}^{dt} QTp_{dt/t(s)} = QT_{d(s)}, \text{For } 1, \ldots, dt, 1, \ldots, s \tag{14}$$

3. Application of the model

In this section, the proposed model is applied to determine the optimal waste allocation plan of a municipal solid waste management system in a continuous five time periods. The studied area includes three communities, and the municipal solid waste management system is constituted by three local collection centers, two regional distribution centers, two incineration plants and one landfill. The parameters of local waste collection centers are presented in Table 1. It is noteworthy that all the numerical values of the parameters in this illustrative example are unitless.

Table 1. Parameters of local waste collection center

Parameter	Community	Period				
		s=1	s=2	s=3	s=4	s=5
$AL_{c(s)}$	c=1	3500000	3750000	3900000	4050000	4200000
	c=2	5000000	5300000	5550000	5800000	6300000
	c=3	3200000	3300000	3400000	3500000	3600000
$SW_{c(s)}$	c=1	85500	92000	94500	99200	102500
	c=2	106000	113500	121000	132000	135800
	c=3	68000	68500	69200	70150	72000
$WCC_{c(s)}$	c=1	35	38	41	45	51
	c=2	32	34	37	40	43
	c=3	35	37	40	42	45
$MAX_{c(s)}$	c=1	105000	105000	105000	105000	105000
	c=2	120000	120000	120000	120000	120000
	c=3	85000	85000	85000	85000	85000
$POL_{af(s)}$	af=1	32133	33110	33575	34123	35501
	af=2	45101	45893	46355	46908	47366
	af=3	26105	27122	27833	28206	28633

In this example, all the three communities are influenced by the municipal solid waste management system, so the set of communities (*c*) equals to the set of affected areas (*af*). The parameters of regional waste distribution centers, incineration plants as well as landfill are illustrated in Tables 2, 3 and 4, respectively. For those three levels of facilities, the environmental pollution indicator is also given so that the environmental pollution of the municipal solid waste management system can be calculated. The population of each affected community introduced in Table 1 adjusts the overall negative environmental impact and risk to relevant communities, and this will push the environmental pollution objective tightening towards the minimum impact on most populated areas.

Table 2. Parameters of regional waste distribution center

Parameter	Distribution	Period				
		s=1	s=2	s=3	s=4	s=5
$AL_{dt(s)}$	dt=1	5500000	5650000	5800000	6000000	6150000
	dt=2	4500000	4600000	4700000	4800000	4900000
$WDtC_{dt(s)}$	dt=1	25	27	28	30	31
	dt=2	27	29	30	32	33
$MAX_{dt(s)}$	dt=1	155000	155000	185000	185000	185000
	dt=2	135000	135000	135000	135000	135000
$MIN_{dt(s)}$	dt=1	70000	70000	70000	70000	70000
	dt=2	65000	65000	65000	65000	65000
$EP_{dt(s)}$	dt=1	1.5	1.5	1.5	1.65	1.65
	dt=2	1.3	1.3	1.3	1.3	1.3

Table 3. Parameters of waste treatment plant

Parameter	Treatment	Period				
		s=1	s=2	s=3	s=4	s=5
$AL_{t(s)}$	t=1	10250000	10350000	10500000	10750000	10900000
	t=2	8500000	8800000	8900000	9050000	9200000
$WTC_{t(s)}$	t=1	18	20	20	21	21
	t=2	19	19	22	22	22
$MAX_{t(s)}$	t=1	110000	110000	110000	110000	110000
	t=2	90000	90000	90000	90000	90000
$MIN_{t(s)}$	t=1	70000	70000	70000	70000	70000
	t=2	60000	60000	60000	60000	60000
$EP_{t(s)}$	t=1	2.6	2.6	2.7	2.7	2.7
	t=2	2.2	2.3	2.3	2.3	2.4

Table 4. Parameters of waste disposal facility

Parameter	Treatment	Period				
		s=1	s=2	s=3	s=4	s=5
$AL_{d(s)}$	d=1	4500000	4550000	4600000	4650000	4700000
$WDC_{d(s)}$	d=1	13	14	15	16	17
$MAX_{d(s)}$	d=1	250000	245000	230000	220000	210000
$MIN_{d(s)}$	d=1	50000	50000	50000	50000	50000
$EP_{d(s)}$	d=1	4.5	4.9	5.3	5.7	6.2

Table 5 presents the distance between local waste collection centers to other downstream facilities within municipal solid waste management system. Table 6 gives the unit inter-facility transportation cost of solid waste. The waste locally collected will be first sent to regional distribution center for separation and pre-treatment, and the direct transportation of waste between local collection center to treatment plant or landfill is therefore impossible, and this type of unit transportation cost of municipal solid waste is not listed in this table.

Table 5. Distance between different facilities

Community	Distribution		Treatment		Disposal
	dt=1	dt=2	t=1	t=2	d=1
c=1	8	10	16	32	45
c=2	12	10	20	29	34
c=3	18	6	18	19	30

Table 6. Parameters of inter-facility transportation of municipal solid waste

Facility		Distribution		Treatment		Disposal	Period				
		dt=1	dt=2	t=1	t=2	d=1	s=1	s=2	s=3	s=4	s=5
Community	c=1	√					14	15	15	17	18
	c=1		√				11	12	13	14	14
	c=2	√					17	18	19	22	22
	c=2		√				12	13	15	16	17
	c=3	√					23	25	27	28	28
	c=3		√				10	14	15	17	18
Distribution	dt=1			√			8	9	10	11	11
	dt=1				√		10	10	11	12	14
	dt=1					√	15	16	17	18	19
	dt=2			√			13	14	15	16	17
	dt=2				√		8	9	9	10	11
	dt=2					√	13	13	13	14	14

The mathematical model is programmed in Lingo package and run at a personal laptop. Due to the small size of the question, the optimal solution of cost objective, environmental pollution objective as well as the composite objective can be calculated within 1 second. The cost optimization and environmental pollution optimization are first solved individually, and waste allocation of both individual objective functions in the studied period is presented in Tables 7 and 8. The optimal individual cost over the studied time horizon is 401421800, and it is 26602910000 for the optimal individual environmental pollution.

Table 7. Optimal waste allocation for cost-minimization objective

Transportation of waste	Period				
	s=1	s=2	s=3	s=4	s=5
$QTp_{c=1/dt=1(s)}$	85500	92000	94500	99200	102500
$QTp_{c=1/dt=2(s)}$					
$QTp_{c=2/dt=1(s)}$	39000	47000	55200	67150	72800
$QTp_{c=2/dt=2(s)}$	67000	66500	65800	64850	63000
$QTp_{c=3/dt=1(s)}$					
$QTp_{c=3/dt=2(s)}$	68000	68500	69200	70150	72000
$QTp_{dt=1/t=1(s)}$	110000	74000	84700	101350	110000
$QTp_{dt=1/t=2(s)}$		65000	65000	65000	65300
$QTp_{dt=2/t=1(s)}$					
$QTp_{dt=2/t=2(s)}$	65000				
$QTp_{dt=1/d=1(s)}$	14500				
$QTp_{dt=2/d=2(s)}$	70000	135000	135000	135000	135000

Table 8. Optimal waste allocation for pollution-minimization objective

Transportation of waste	Period				
	s=1	s=2	s=3	s=4	s=5
$QTp_{c=1/dt=1(s)}$					
$QTp_{c=1/dt=2(s)}$	85500	92000	94500	99200	102500
$QTp_{c=2/dt=1(s)}$	87000	86500	115800	96200	103300
$QTp_{c=2/dt=2(s)}$	19000	27000	5200	35800	32500
$QTp_{c=3/dt=1(s)}$	68000	68500	69200	70150	72000
$QTp_{c=3/dt=2(s)}$					
$QTp_{dt=1/t=1(s)}$	65000	65000	70000	110000	85300
$QTp_{dt=1/t=2(s)}$	90000	90000	90000		90000
$QTp_{dt=2/t=1(s)}$	5000	5000			24700
$QTp_{dt=2/t=2(s)}$				90000	
$QTp_{dt=1/d=1(s)}$			25000	56350	
$QTp_{dt=2/d=2(s)}$	99500	114000	99700	45000	110300

A significant difference of periodic waste allocation can be observed in those two different scenarios. For the local waste collection center at community *c*=3, all the collected solid waste is sent to distribution center *dt*=2 in individual cost optimization scenario due to the predominant advantage of the low unit transportation cost between those two facilities, however, the short distance between them also lead to a much higher value of $\frac{EP_{dt(s)}QT_{dt(s)}}{DS_{dt/af}}$ in the environmental pollution objective, and because of this reason, all the collected waste at community *c*=3 are allocated to distribution center *dt*=1 in the individual environmental pollution optimization scenario even through the environmental pollution indicator of *dt*=1 is slightly greater than that in *dt*=2.

In individual cost optimization scenario, most waste at distribution center *dt*=1 is distributed to the incineration plants due to the much lower unit transportation cost, however, because of the lower unit processing cost of landfill, it becomes the primary destination of the waste at distribution center *dt*=2 where the unit transportation cost to incineration plants and landfill are similar. In individual environmental pollution optimization scenario, the waste treated at incineration plant *t*=1 is minimized due to the large value of $\frac{EP_{t(s)}QT_{t(s)}}{DS_{t/af}}$ resulting from the small distance between incineration plant *t*=1 and affected communities. Besides, the allocation of waste to landfill is less in the individual environmental pollution optimization scenario due to the large value of environmental pollution indicator of landfill.

The optimal value of individual cost and individual environmental pollution can then be brought into the composite objective function Eq. (3), and the optimal value of composite objective can be calculated with given ∂_C and ∂_p. Those two adjustment parameters determine the relative importance of system cost and environmental pollution of the municipal solid waste system, which significantly influence the decision-making of long term allocation of solid waste to different facilities. In this paper, ten different scenarios with incremental value of ∂_C are defined, and it equals to 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9, respectively. Figure 2 illustrates the comparison of the optimal value of the composite objective functions in those ten defined scenarios.

As shown in the figure, the value of the composite objective function increases with the increase of the value of parameter ∂_C. Besides, the optimal value of Eq. (3) equals to 1 when ∂_C equals to 0 or 1, and that represents the individual cost optimization and individual environmental pollution optimization. The long-term performance of municipal solid waste management system becomes much better when the optimal value of the composite objective function approaches to 1, so for this illustrative case, the system performance becomes much better when the environmental pollution objective plays more important role in the decision-making of the long-term waste allocation plan.

The focus on environmental pollution of municipal solid waste management system may lead to extremely high cost, and the optimal balance of cost objective and environmental pollution is therefore emphasized. Herein, a compromising scenario with ∂_C equals to 0.5 is detailed in Table 9. As shown in the table, there is a significant difference of waste allocation over the five periods from that in individual cost objective and individual environmental pollution objective, and a more even allocation of waste to different facilities in the studied time horizon can be observed in this scenario. The balance of those two objective functions is optimized for the given numerical value of ∂_C. Therefore, the proposed model provides an effective solution for the long-term operational planning of the municipal solid waste management system.

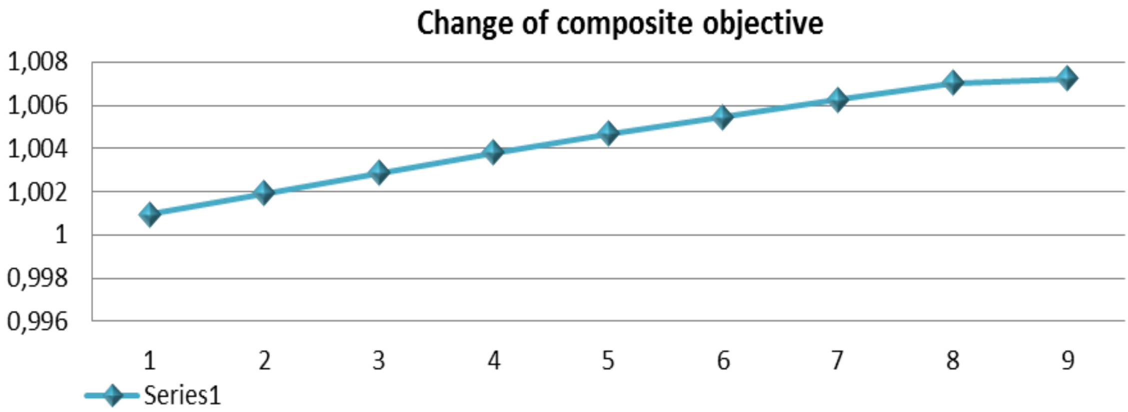

Figure 2. Comparison of the optimal value of the composite objective functions in the defined ten scenarios

Table 9. Optimal waste allocation when ∂_C equals to 0.5

Transportation of waste	Period				
	s=1	s=2	s=3	s=4	s=5
$QTp_{c=1/dt=1(s)}$					
$QTp_{c=1/dt=2(s)}$	85500	92000	94500	99200	102500
$QTp_{c=2/dt=1(s)}$	56500	70500	80500	96200	103300
$QTp_{c=2/dt=2(s)}$	49500	43000	40500	35800	32500
$QTp_{c=3/dt=1(s)}$	68000	68500	69200	70150	72000
$QTp_{c=3/dt=2(s)}$					
$QTp_{dt=1/t=1(s)}$	70000	70000	70000	110000	11000
$QTp_{dt=1/t=2(s)}$		69000	79700	56350	65300
$QTp_{dt=2/t=1(s)}$					
$QTp_{dt=2/t=2(s)}$	90000	21000	10300	33650	24700
$QTp_{dt=1/d=1(s)}$	54500				
$QTp_{dt=2/d=2(s)}$	45000	114000	124700	101350	110300

4. Conclusion

This paper has presented a bi-objective dynamic optimization model for long-term planning of municipal solid waste management system. Previously, most literature focuses on the methods and models for the network design and location problems of waste treatment facilities (e.g. incinerator, landfill, etc.) and transfer station, but this study aims to develop navel methods and computation model for determining the optimal long-term operation plan of municipal solid waste management system. The model developed in this study is a bi-objective linear programming model which simultaneously optimizes the system operating cost and environmental pollution of municipal solid waste management system, and an illustration is also presented for a deep insight of the model application.

Future improvement can be focused on two aspects. First, the consideration of the entire reverse supply chain of waste management should be taken into account. With the promotion of sustainable development, many types of municipal solid waste has been considered as the “raw material” of the reverse supply chain, and more alternatives for waste treatment, recycling, reuse and remanufacturing have dramatically increased the complication and complexity of the reverse network of municipal solid waste management system. Therefore, the development of decision support tools for the entire reverse supply chain of waste management is initially suggested. Second, some parameters are impossible to be predicted precisely for the given time periods, and methods for effectively dealing with the uncertain parameters are therefore important for the decision support model and suggested for further improvement.

Nomenclature

Subscripts

s	Number of defined time periods;
c	Number of local waste collection centers;
dt	Number of regional waste distribution centers;
t	Number of waste treatment plants;
d	Number of disposal facilities;
af	Number of affected communities;

Parameters (The meaning of the parameters subjects to the subscripts)

Al	Annualized investment;
WCC	Unit collection and processing cost at local waste collection center;
WDtC	Unit processing cost at regional waste distribution center;
WTC	Unit processing cost at waste treatment plant;
WDC	Unit processing cost at waste disposal facility;
WTpC	Unit waste transportation cost;
QT	Waste amount processed;
QTp	Waste amount transported;
POL	Population of affected community;
EP	Environmental pollution indicator;
DS	Distance between waste management facility and affected community;
MAX	Maximum capacity;
MIN	Minimum required waste quantity;
SW	Waste generation at each community;

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