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# Sustainable design for locating sorting centers of municipal solid waste

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**Abstract**

Recycling of municipal solid waste (MSW) as a process for closing the supply chain of many products is mainly the value of this category of products after use cannot be improved. It cannot be denied that in the past decade process of recycling urban waste material in Iran has made enormous progress. However, compared to the other countries, there is a weak sense. In this study, a bi-objective integer programming model to minimize overall costs and maximize profits at sorting centers modeled. The aim is to optimize the costs and benefits and general interaction among us is dimensionally permanent In this study, all three dimensions of sustainability, including the technical, environmental and social considered in to the proposed model. To cope with bi-objectiveness of the problem, a multi-choice goal programming (MCGP) approach applied. Then, the model is solved by CPLEX solver to test its validity. Finally, the computational results show the applicability of the proposed methodology in the real world.

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## 1. Introduction

Municipal solid waste (MSW) recycling process for closing the supply chain of many products which are mainly used after the value of this category of products can be improved. Successful implementation of the recovery process requires the active centers of collection and separation of municipal waste.

It cannot be denied that in the past decade process of recycling urban waste material in Iran has been significant progress however, there are still obstacles to reach the desired place and ahead of the countries in this industry is feeling weak. In the debate over waste recycling process will first need to define the role of public and private companies and the general community on the collection and storage of waste we produce. In general perspective, one

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can say that the government must also increase environmental awareness in relation to economic incentives activities related to define the recycling process. In general, the role of government in society, the more motivated the recycling of urban waste in order to protect the health of the environment the use of economic incentives as an efficient tool to achieve this is to inherit. In order to recycle materials such as glass, metal and plastic requires commitments between the government and company's production. Even in some cases the penalties to be considered. All of this talk of green supply chain (GSCM) is important. One of the main challenges of coordination between different departments is in the process of recycling. Hence one of the main problems and challenges in the process of recycling of how to implement successfully manage to collect recyclable materials from the crowd of consumers (Dahlén and Lagerkvist, 2010). Collecting recyclable waste also bring problems Among them are the large area to area transportation costs related to the city's waste The manner in which the transportation of waste to be recycled and place a large impact on the parameters of environmental and human lives. In recent years due to the importance of social responsibility in one of the business units have attracted more attention to the social costs of job stability, worker safety, public health and the ability of technology to products.

In this study, to consider ways to culture in the crowd for sorting and locating the correct training centers and social workers have tried to cut costs and in general, we contribute to the development of more sustainable (Khademolqorani, 2018).

Urban waste recycling is a necessary process for closing the supply chain of many products, which cannot improve the value of these products after usage. It cannot be denied that in the past decades, the process of waste recycling. There has been a remarkable city in Iran, but it still has some weaknesses in other countries that need to be addressed to eliminate them. These include the high cost of collecting and sorting waste and, in general, the process of recycling (Erkut et al., 2008). In order to recycle materials such as glass, metal, and plastics, there is a need for comprehensive commitments Government and corporate production. In general, one can say that with increasing environmental awareness, the government should define economic incentives in relation to the activities related to the recycling process. Even in some cases the government has imposed fines. All of this is discussed in the discussion. Green Supply Chains (GSCM) is a very important issue to be followed in strategic decisions. One of the main challenges in the recycling process is the coordination between the different sectors. Hence, one of the main challenges and challenges in the recycling process is the implementation of successful management for the collection of materials recycled from the population of consumers. Recycling waste collection also has its own problems, including collection, transportation, sorting, etc. It is possible to highlight the area of interest and the cost of transporting municipal waste. Thus, the way in which waste is transported and the recycling areas have a great impact on the environmental parameters and human life. In general, the reverse logistics network decision strategy, which included a selection of a delivery method, location and capacity for recycling, and its re-operations, was proposed by Fleischmann et al. (1997 and 2001). Subsequently, in 2009, reverse logistics locator models that could be split in: 1. issues that are reversed networks with the flow of integrated network (closed loop) and 2. issues that focus on recycling activities. Fleischmann et al. (2001) developed a model for the design of a reverse logistics network, which consists of three levels of facilities (plans, warehouses, and centers), as well as Lu and Bostel (2007), a simple model for recycling systems was put forward by Jayaraman et al. (2003), to models and solutions that introduced reverse-distribution problems involving returned products, recycled products, consumer products, and high-end product returns. Alumur et al. (2012) presented a mathematical model for a multi-period reverse logistics network that included several features, such as capacity development, size-dependent capacities, variable operating costs, and a profit-oriented target function. A two-stage location model, which decided to locate the middle facility for the recovery of sand from construction waste, was proposed by Barros et al. (1998) and Dekker et al. (2012). Cruz-Rivera and Ertel (2009) investigated facility location problems (FLPs) without capacity constraints for implementing the final vehicle management cycle. Lee and Dong (2009) addresses the issue of designing logistics networks for the recycling of end-of-life cycles of computer products. In addition, other articles of the model Optimized for the design of a supply chain network with environmental issues. Wang et al. (2011) proposed a multi-objective model for designing a supply chain network that includes decisions on environmental investment. Dekker et al. (2012) reviewed a number of articles that feature location-matching models for the design of sustainable circuits. In particular, few articles review the reverse logistics models for urban waste management. Erkut et al. (2008) proposed a multi-criteria model for solving a locational problem for management of municipal solid waste facilities in northern Greece. Multiple functionalities are related to the economy and environmental aspects. Ghiani et al. (2012) proposed a mathematical model to locate facilities for the delivery of rubbish boxes in an urban waste management system as long-term decisions. Design decisions on many of the key parameters such as costs, demands, capacities, intervals, and delivery times that might change sustainability issues were introduced by Chen et al. (2006). For this purpose, articles that are theoretical and special to the aspect cover the facility location, which selects a series of useful state-of-the-art information, enforces recovery systems, and avoids the implementation of costly decisions. For example, Daskin et al. (1997) addressed random probabilities that can affect probabilities And scenario design. Colvero et al. (2018) could apply a geographic information system (GIS) to find the best areas for locating of municipal solid waste management facilities. Some other related works have been done on routing decisions or both locational routing decisions such as Aydemir-Karadag (2018), Babaee Tirkolaee et al. (2016), Tirkolaee et al. (2018a, 2018b and 2018c) and Samanlioglu (2013).

As it is obvious, there is not a comprehensive research investigating the locational decisions with sustainability point of view, which is put forward in this research. To this end, a novel mathematical model is developed to formulate the problem.

The remaining sections of the paper are organized as follows. The model development is described in Section 2. Section 3 introduces the proposed solution approach of the research. The computational results are discussed in Section 4. Finally, the concluding remarks and outlook of the research are given in Section 5.

## 2. Model development

In this section, the proposed model of the problem is presented. First, the main assumptions are described as follows, and then the sets, parameters, variables, objective functions and constraints are introduced.

- There are several candidate locations to establish sorting centers within a network.
- There are several customer areas where wastes are generated.
- There is a planning horizon defined for strategic and tactical decisions.

To understand the mechanism of the sorting centers, a schematic view is given in Figure 1.

**Fig. 1.** The schematic view of a sorting center.

### 2.1. Indices

| | |
|---|---|
| $I = \{1,2,\dots,I\}$ | Set of candidate locations for sorting centers |
| $J = \{1,2,\dots,J\}$ | Set of customer areas |
| $T = \{1,2,\dots,T\}$ | Set of time periods |

### 2.2. Parameters

| | |
|---|---|
| $q_{jt}$ | Amount of recyclable materials in area *j* in period *t* |
| $Q_{it}$ | Capacity of sorting center located at point *i* in period *t* |
| $y_t$ | Budget allocated to the sorting centers in period *t* |
| $N_{jt}$ | The separation amount of area *j* in period *t* |
| $fi_{it}$ | The number of permanent job opportunities created at point *i* in period *t* (such as managerial job opportunities) |
| $fj_{jt}$ | A number of permanent job opportunities created for people in area *j* in period *t* |
| $fl_{it}$ | The number of days lost due to occupational hazards during the establishment of centers in point *i* in period *t* |
| $d_{it}$ | The number of workers who can be employed at point *i* in period *t* |
| $\delta$ | The cost of recruitment |
| $P_{it}$ | Benefits from the use of more workers in point *i* in period *t* |
| $YY_t$ | Financial allocation to the sorting center in period *t* |
| $C_{ijt}$ | Transportation costs of all the recyclable materials from area *j* to point *i* in period *t* |
| $g_{it}$ | Operational cost for operating a sorting center in point *i* in period *t* |
| $F_{it}$ | The cost of establishing a sorting center at point *i* in period *t* |

| | |
|---|---|
| $h_j$ | Unit penalty cost for failing to collect recyclable materials in area *j* |
| $\mu_{jt}$ | Cost of separating recyclable materials in area *j* at period *t* |
| $S_{jt}$ | Cost of creating the separation machines of area *j* at period *t* |
| $CB_{it}$ | Budget allocated for the recruitment in point *i* at period *t* |
| $P$ | Maximum number of established sorting centers |
| $LP$ | Limited batch of pockets in sorting centers |
| $M$ | A very large number |

### *2.3. Decision variables*

| | |
|---|---|
| $Z_{it}$ | A binary variable takes the value of 1 if sorting center *i* is established in period *t*, otherwise, it is zero |
| $Y_{it}$ | A binary variable takes the value of 1 if sorting center *i* is activated and busy in period *t*, otherwise, it is zero |
| $k_{it}$ | A binary variable takes the value of 1 if the permanent job opportunities created in sorting center *i* in period *t*, otherwise the order is zero. |
| $kk_{jt}$ | A binary variable takes the value of 1 if public participation formed in area *j* at period *t* |
| $ZZ_{ijt}$ | A binary variable takes the value of 1 if there is a link between area *j* and point *i* in period *t*, otherwise zero is considered |
| $I_{jt}$ | The amount of generated recyclable materials in area *j* at period *t* |
| $X_{ijt}$ | The percentage of recyclable materials generated in area *j* which is collected by the center in point *i* at period *t* |
| $b_{jt}$ | The number of packages that municipality distributed in area *j* at period *t* for the culture creation |
| $y_t$ | Amount of non-allocated budget in period *t* |

## 3. Mathematical model

As mentioned, the location of waste sorting centers should be designed which could minimize the costs of all the waste sorting centers and fixed and variable areas and maximize jobs to help develop a more dimensionally permanent. Now it's time to mixed integer programming problem's final grade point average, be introduced before formulating the final issue to define the parameters described above.

$$\text{minimize } Z = \sum_i \sum_j \sum_t c_{ijt} x_{ijt} q_{jt} + \sum_i \sum_t F_{it} z_{it} + \sum_j \sum_t \mu_{jt} N_{jt} k_{jt} + \sum_i \sum_t g_{it} y_{it} + \sum_j \sum_t S_{jt} b_{jt} \qquad (1)$$

$$\text{maximize } W = \sum_j \sum_t kk_{jt}\; fj_{jt} + \sum_j \sum_t (1 - k_{it})\, fi_{it} - \sum_i \sum_t k_{it} fl_{it} \qquad (2)$$

subject to

$$\sum_{i \epsilon I} CB_{it} - \left( \sum_{i \epsilon I} \sum_{j \epsilon J} C_{ijt} X_{ijt} q_{jt} + \sum_{i \epsilon I} f_{it} z_{it} + \sum_{i \epsilon I} g_{it} y_{it} \right) + y_{t-1} = y_t \quad \forall t \in T, \tag{3}$$

$$\sum_{j \in J} q_{jt} X_{ijt} \le Q_i Y_{it} \quad \forall i \in I, \forall t \in T, \tag{4}$$

$$\sum_{i \in I} x_{ijt} z_{ijt} \le 1 \quad \forall j \in J, \forall t \in T, \tag{5}$$

$$X_{ijt} \ge ZZ_{ijt} \quad \forall i \in I, \forall j \in J, \forall t \in T, \tag{6}$$

$$Z_{ijt} \le M\, ZZ_{ijt} \quad \forall i \in I, \forall j \in J, \forall t \in T, \tag{7}$$

$$ZZ_{ijt} \ge Z_{ijt} - M\left(1 - X_{ijt}\right) \quad \forall i \in I, \forall j \in J, \forall t \in T, \tag{8}$$

$$1 - \left( \sum_{i \in I} x_{ijt} z_{ijt} \right) q_{2jt} = I_{jt} \quad \forall j \in J, \forall t \in T, \tag{9}$$

$$Y_{it} \ge Y_{i\,(t-1)} \quad \forall i \in I, \forall t \in T, \tag{10}$$

$$Z_{it} \ge Y_{it} - Y_{i(t-1)} \quad \forall i \in I, \forall t \in T, \tag{11}$$

$$Z_{it} \ge Y_{it} \quad \forall i \in I, \forall t \in T, \tag{12}$$

$$\sum_{i \in I} \sum_{t \in T} Z_{it} \le P \tag{13}$$

$$\sum_{j \in J} ZZ_{ijt} \le Y_{it} M \quad \forall i \in I, \forall t \in T, \tag{14}$$

$$\sum_{j \in J} ZZ_{ijt} \ge Y_{it} \quad \forall i \in I, \forall t \in T, \tag{15}$$

$$k_{it} \le Y_{it}\, M \quad \forall i \in I, \forall t \in T, \tag{16}$$

$$k_{it} \ge Y_{it} \quad \forall i \in I, \forall t \in T, \tag{17}$$

$$b_{jt} \ge kk_{jt}\, LP \quad \forall j \in J, \forall t \in T, \tag{18}$$

$$I_j \le \left(1 - kk_{jt}\right) M + LP \quad \forall j \in J, \forall t \in T, \tag{19}$$

$$Z_{it} \in \{0,1\} \quad \forall i \in I, \forall t \in T, \tag{20}$$

$$X_{ijt} \in \{0,1\} \quad \forall i \in I, \forall j \in J, \forall t \in T, \tag{21}$$

$$I_{jt} \ge 0 \quad \forall j \in J, \forall t \in T, \tag{22}$$

$$b_{it} \ge 0 \quad \forall i \in I, \forall t \in T. \tag{23}$$

First objective function (1) is to minimize the total cost of transportation and setup costs, the cost of separation by the people operating costs of sorting centers, the cost of culture among the population and ultimately penalties arising from failure to collect the recycled materials. The second objective function (2) maximizes the fixed and variable employment opportunities in the areas of waste collection through minimizing the days lost due to occupational hazards sorting centers as well as days lost due to the labor treatment in the areas. Constraint (3) ensures the financial budget for conducting the previous operating periods against the next periods without any guarantee. Constraint (4) refers to the maximum capacity of collection points. Constraints (5), (6), (7) and (8) indicate the total per of recycled materials from areas most centers is equal to one. Constraint (9) indicates that the total sent from the regions to the center collecting recycled materials recycled remaining in the areas of zero. In other words, the recycled materials due to budget constraints can be delivered by batch centers. Constraints (10), (11), and (12) indicate that their sorting center must of course be more active. Constraint (13) limits the number of sorting centers.

Constraints (14) and (15) indicate that a sorting center in period t must have at least the period before it becomes active. Constraints (16) and (17) state that permanent jobs can be created in the sorting centers when sorting centers have already been established. Constraints (18) and (19) indicate that the number of packets culture in each area is limited. Constraints (20)-(23) indicated that the decision variables are positive.

## 4. Multi-choice goal programming considering utility function

Goal Programming (GP) approach is one of the most efficient methods to solve the multi-objective optimization, which minimizes inappropriate deviations of the ideal goals. The main concept of GP is to consider some objective values as expectation level for objective functions. Then, it tries to minimize the sum of these deviations from the ideal levels (Chang, 2011).

Due to the real world uncertainty, the decision makers may prefer to set multiple ideal levels for each objective. To deal with this issue, Multi-choice Goal Programming (MCGP) considers a range for ideal levels. Furthermore, the general utility function is added to the problem in order to maximize the decision makers expected utility (Chang, 2011).

In this paper, a developed variant of MCGP is applied to solve the proposed bi-objective model which was first introduced by Chang (2008). The proposed model is as follows:

$$\text{minimize } \sum_k [\beta_k^d (d_k^+ + d_k^-) + \beta_k^\delta \delta_k^-]$$

subject to

$$\begin{aligned}
&\lambda \le \frac{U_{k,\max} - y_k}{U_{k,\max} - U_{k,\min}} && \forall k \in K, \\
&f_k(X) + d_k^- - d_k^+ = y_k && \forall k \in K, \\
&\lambda_k + \delta_k^- = 1 && \forall k \in K, \\
&U_{k,\min} \le y_k \le U_{k,\max} && \forall k \in K, \\
&d_k^- . d_k^+ = 0 && \forall k \in K, \\
&d_k^-, d_k^+, \delta_k^-, \lambda_k \ge 0 && \forall k \in K,
\end{aligned} \tag{24}$$

Eqns. (1)-(23).

where $U_{k,min}$ and $U_{k,max}$ denote the lower and upper range of $k^{\text{th}}$ ideal level, respectively, and $y_k$ is the continuous decision variable. Here, $d_k^+$ and $d_k^-$ are positive and negative deviations of $f_k$(X) from $y_k$, respectively. $\delta_k^-$ is the normalized deviation of $y_k$ from $U_{k,min}$ and $\beta_k^\delta$ represents the weight of $\delta_k^-$ and finally, $\lambda_k$ is the utility value.

If needed, the objective function of Chang can be also normalized as follows (Chang, 2011):

$$\text{minimize } \sum_k [\beta_k^d \cdot \frac{d_k^- + d_k^+}{f_k^- - f_k^+} + \beta_k^\delta . \delta_k^-] \tag{25}$$

where $f_k^+ = \{\min f_k(X)\}$ and $f_k^- = \{\max f_k(X)\}$. Therefore, the final model is formulated as follows:

$$\text{minimize } \beta_1^d (\frac{d_1^+ + d_1^-}{f_1^+ - f_1^-}) + \beta_2^d (\frac{d_2^+ + d_2^-}{f_2^- - f_2^+}) + \beta_1^\delta \delta_1^- + \beta_2^\delta \delta_2^- \tag{26}$$

subject to

$$\lambda_1 \le \frac{U_{1,\max} - y_1}{U_{1,\max} - U_{1,\min}} \tag{27}$$

$$\lambda_2 \le \frac{U_{2,\max} - y_2}{U_{2,\max} - U_{2,\min}} \tag{28}$$

$$Z + d_1^- - d_1^+ = y_1 \tag{29}$$

$$W + d_2^- - d_2^+ = y_2 \tag{30}$$

$$\lambda_1 + \delta_1^- = 1 \tag{31}$$

$$\lambda_2 + \delta_2^- = 1 \tag{32}$$

$$U_{1,\min} \le y_1 \le U_{1,\max} \tag{33}$$

$$U_{2,\min} \le y_2 \le U_{2,\max} \tag{34}$$

Eqns. (1)-(23). (35)

## 5. Computational results

In this section to evaluate the validity of the problem, 3 instances with small to large sizes were generated randomly. Also, the parameters are randomly generated using a uniform distribution function. Then the problems are executed on a laptop with Intel Core i7 (8GB RAM) specs by GAMS software and the CPLEX linear solver. The input information of the problems space is given in Table 1. Moreover, the parameters values are taken randomly using a uniform distribution.

**Table 1**. Input information of the instance problem.

| Problem | *I* | *J* | *T* |
|---|---|---|---|
| 1 | 12 | 5 | 4 |
| 2 | 20 | 10 | 5 |
| 3 | 40 | 15 | 10 |

The obtained results are represented in Table 2. As it is clear, the obtained values for the objective functions have a significant deviations from the ideal values; i.e., the values of $y_1$ and $y_2$. To this reason, the obtained values for the positive deviation from $Z$ and the obtained values for the negative values from $W$ are quite large. These variables take a bigger value in the problem with larger size. This shows that the decision-making process may be difficult in the real world and may be a bit far from the optimal values.

**Table 2**. Computational results of GP by CPLEX.

| Variables | Problem 1 | Problem 2 | Problem 3 |
|---|---|---|---|
| $y_1$ | 135957029.031 | 425079101.294 | 1182816817.060 |
| $y_2$ | -11092.3 | -30947.7 | -55176.1 |
| $Z$ | 145682033.154 | 437279190.715 | 1219353023.309 |
| $W$ | -12016.306 | -32236.800 | -60854.647 |
| $d_1^+$ | 9725004.123 | 12200089.421 | 36536206.249 |
| $d_2^-$ | 924.006 | 1289.100 | 5678.547 |
| Run time (s) | 1.051 | 38.690 | 137.068 |

On the other hand, to assess the capability of the proposed solution tool, the run time comparison of different generated solutions is provided in Figure 2. As we can see, it grows rapidly when the problem size becomes larger and larger. This may reveal the necessity of using the alternative tools such as metaheuristics to solve the real world problems.

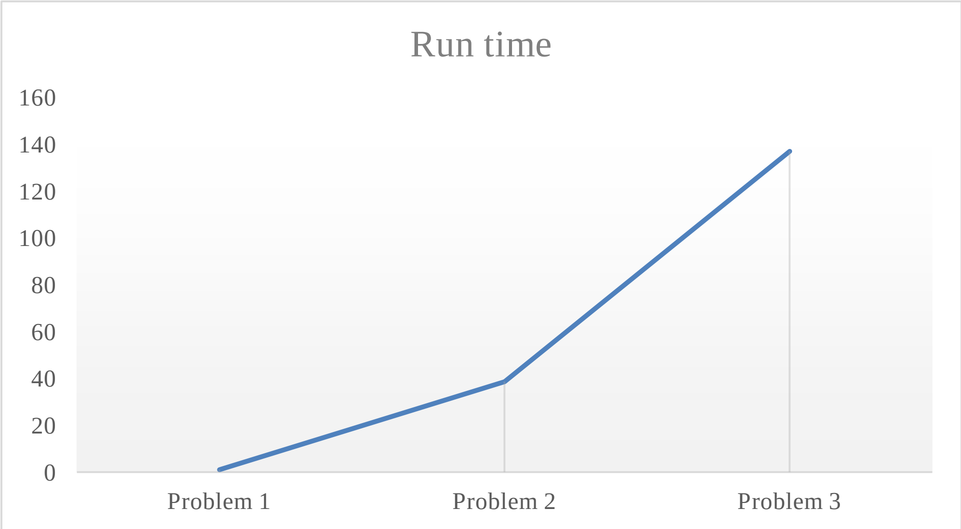


**Fig. 2.** Run time comparison in different problems.

## 6. Conclusion

Solid waste management includes the processes of collecting, treating, and disposing of solid material that is discarded because it has served its purpose or is no longer useful. Improper disposal of municipal solid waste can create unsanitary conditions, and these conditions in turn can lead to pollution of the environment and to outbreaks of diseases. The tasks of solid waste management present complex technical challenges. They also pose a wide variety of administrative, economic, and social problems that must be managed and solved. In this paper, an efficient methodology was proposed to deal with this problem in terms of finding the best locations of sorting centers in an urban areal considering job opportunities to be maximized. To this end, a bi-objective mathematical model was developed to cover the main problem with the aim of total cost minimization besides job opportunities maximization. A multi-choice goal programming approach was applied and implemented by CPLEX solver to solve different problems.

For future studies, Pareto-based solution methods such as multi-objective metaheuristics and ε-constraint method can be applied to solve the model. Moreover, other real world assumptions such as routing decision may be incorporated in the model to make more comprehensive decisions.

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