Multi-objective evaluation of site selection of Municipal Solid Waste Transfer Stations

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Municipal solid waste has become one of the most serious public hazards in the world today. The objective of my study is to decide the location of the storage and sorting facilities across the end-of-life municipal solid waste (MSW) transfer network because the building of transfer station (TS) which connects the source of waste and resource recovery system by harmless treatment has not received too much attention in China via designing and proposing a multi-objective modeling in reverse logistic network with consideration of economical perspective (cost) and environmental impact assessment.
Keywords: Municipal Solid Waste, Transfer System, Location Problem, Life Cycle Assessment

1 Introduction

Since the beginning of the 21st century, with the rapid growth of the domestic economy, China's urban construction has also been carried out on a large scale, and the urban infrastructure has been gradually improved. Municipal solid waste (MSW) is a heterogeneous waste stream that is an inevitable part of daily life and can seriously damage the environment and human health. As the core of the waste transfer system, the waste transfer station is an important site for waste storage, transfer, compression, and classification.

1.1 Current Problems

In recent years, the main criteria used to decide on the location of a transfer station has traditionally been the minimization of transport costs, since it is cheaper to transport excessive amounts of waste over long distances in large loads than in small ones. Therefore, there are still a lot of problems need to be considered. In this study, I am going to consider the economic factor and environmental factor in order to compare the feasibility of using a transfer station integrated within a waste management system. Applying the Life Cycle Assessment technique will enable me to obtain an objective parameter that quantifies the environmental impact of transportation and of operating a transfer station.

1.2 Objective

The study introduces a multi-objective optimization model for the Pareto optimal location of the MSWTS in a MSW management system What's more, I hope to propose a model addresses the economic, environmental, and social perspectives of the system by cost optimization, LCA of environmental impact index considering all three dimensions of sustainability. Finally, this model can aid decision makers to locate the optimal sites of municipal solid waste transfer stations under the trade-off between cost and environmental influence of waste collection and transportation via waste transfer stations.

2. Methodology

From the beginning I conducted a semi-structured interview with relative stakeholders to find social and political concerns to solve the cost problem about the construction of transfer stations. Meanwhile, from looking through the statistical yearbook and communication with operators of the transfer station to learn about the fuel combustion during collection and transportation. By then, design a solution of parametric modeling on this topic. Finally, the cost composition and environmental impact indicator could be taken to formulate the objective function and constraints as the proposed method for site selection problem.

2.1 Proposed site selection process

To solve the problem of MSW transfer station site selection with fully consideration on economic level of cost problem, environmental level, and social acceptance problem which is transformed into a cost problem in the objective functions. Firstly, based on the result of the semi-structured interview, I am able to attain the regulations, policies, and currently empirical method of site selection. Meanwhile, it is available to get the economic level of cost composition from the communications with stakeholders, including residents, officers and investors or operators to form the cost objective function. From life cycle assessment on waste transfer station, the environmental level of impact by the operation of TS could be quantified and then form the objective function of environmental influence. For the case study section, I will apply the proposed method to analyze the candidates from the regulation matched sites.

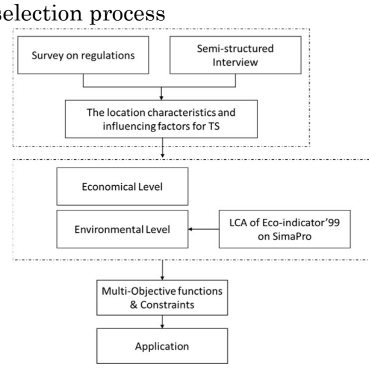

Figure 1 Process of sites selection

2.2 Model Formulation

In this section, I formulate a trade space model for a MSW system consisting of residential communities, transfer stations, and final sanitary waste facility. I assume that all kind of municipal solid waste is transported to the final via transfer station, that is, indirect transportation which by using collection trucks to accumulate the collected MSW at transfer stations, compacting them into modular cubes, and then using semi-trailer trucks to transport the compressed waste to the final facility.

The objective is to determine the following decisions simultaneously:

- The number of transfer stations to be established.
- The location of each transfer station.

The above decisions will be determined by using a multi-objective model that minimizes the total cost of construction includes social acceptance and the total amount of environmental factors index of each transfer station. The mathematical formulation proposed for this problem consists of two objective functions. The first objective function minimizes the total cost of the construction on MSW management facilities and the cost of transportation between them. The second objective function minimizes the total environmental impact index of Eco-Indicator'99 of the facilities and waste transport vehicles.

2.3 Survey on regulations for site selection

The MSW transfer system can be divided into one-time, and twice-times transfer modes. Generally, the one-time transfer system is used in most situations.

2.4 Semi-structured interview with stakeholders

From the semi-structured interview, there are 3 key points should be recognized, current problems on the construction of transfer station, for instance, the cost on the construction is unaffordable for the investors due to the money in social acceptance. The expective numbers of transfer stations planned from the bureau of environmental protection. What is more, their requirements for the transfer station sites selection by the administrative agencies.

2.5 Evaluate the candidates by cost estimation

Research on cost minimization has been a concern from the very beginning. The objective function can generally be expressed by mix integer linear programming. In my study, I developed the equation of direct cost and indirect cost separately as in the following:

Typical function of cost = $\sum_{p=1}^{m}\sum_{j}^{n} c_{pj}x_{pj} + \sum_{p=1}^{m} Mp \bullet (d_p + T \bullet h_p)$(2)

This function represents the direct cost. Where the fixed cost is dp of station construction and maintenance costs is hp (without depreciation) of the waste transfer station at point p∈m, j∈n is the collection point. T represents design service life, and cpj is unit transportation costs per kilometer, xpj represents the transportation volume per kilometer from the transfer station p to collection point j. Mp states whether to build the transfer station at point p.

Total capital, other or contribution cost and demolish cost of the MSW transfer station are computed using equations as following, respectively.

Capital cost = $\sum_{p=1}^{m} M_p l_p + M_p q_p$ (3), where lp is the cost for the land to build a transfer station at the point p. And the q_p is the demolish cost when there are other buildings on the land.

Other and contribution cost = proportion to the land cost as = $\sum_{p=1}^{m} a \cdot M_p l_p$ (4), where a is the proportion rate to the land cost. Other and contribution cost is designed to mitigate NIMBY syndrome and it can be regard as another kind of compensation. The cost will be used to build green field or park or other types of public welfare infrastructure. There are three types of compensation cost that are often used:

1. Empirical compensation b*=$b \cdot r \cdot N$ (5), where b is an environmental compensation of the last NIMBY problem, r represents the One-Year Treasury Bond Yield, and N refers to the number of people will be compensated.
2. Proportion to total cost = $\theta \cdot \omega$ (6), where ω represents other cost, θ represents a proportion to other costs.
3. Proportion to total operated revenue in T years to the transfer station = T·α·R (7), where R equals the sum of waste removal freight plus governmental allowance, α states the proportion to the revenue of a transfer station.

Direct monetary cost of public participation involves the staff time (paid and unpaid), staff expenses, external staff or consultants, fees to participants, participants' expenses, training for staff and participants, administration, venue hire, other event costs (e.g., refreshments, equipment), media, leaflets, monitoring and evaluation fees and so on. The estimation equation could be:

Cost per event (ce) = Total Participation Budget/Number of events, and then,

Public participation cost $= \sum_{p=1}^{m} ce_p Mp(8)$, where ce_p refers to the cost of the public participation activity held in the point p.

Hence, from the discussion above, the overall cost could be defined as the following equation:

Overall cost = CAPEX (CNY) + OPEX (CNY/Year) *T (Year) (9),

whereas the T is the contract period, generally, T equals 15.

2.5 Evaluate the candidates by environmental impact factors estimation

The aim of this study is to incorporate the environmental factor into the decision-making process. To do so, I will examine the advantages that can be gained, as regards the environment, from integrating a transfer station into a waste management system by applying the Life Cycle Assessment (LCA) methodology (ISO 14040). This part is also going to focus on the impact analysis stage in order to obtain an objective parameter that quantifies the environmental impact produced by a system that transports waste directly to the treatment facility as opposed to an alternative system that includes a transfer station. The Life Cycle Assessment methodology was applied to conduct an environmental comparison of the alternative scenarios for the current waste management system. According to ISO 14040 (1997), an LCA comprises four major stages: goal and scope definition, life cycle inventory, life cycle analysis and interpretation of the results. The following is a detailed description of each stage. The phase of Life Cycle Impact Assessment (LCIA) aims to quantify the relative importance of all environmental emissions obtained in the LCI by aggregating them to obtain a unique environmental indicator (ISO 14042, 2000) by using Eco-indicator'99 at SimaPro to calculate environmental impact.

2.5.1 Calculation on EI

The design capacity of the waste transfer station should be based on the amount of garbage collected in the service area and take into account the characteristics of the city's seasonal and economic changes. The specific calculation formula is as follows:

$$Qd = Ks \cdot Qc \quad (1)$$

Qd represents the design scale of the transfer station (transfer volume). *Qc* is the waste collection volume in the service area (annual average). *Ks* is the seasonal fluctuation coefficient of waste discharge. It should be adopted according to local actual data.

In the operation of the transfer station, the process Pr_j of the waste transportation (Pr_{tr}) and the energy consumption (Pre) of the transfer station may produce emissions (W_i), and each type of emissions (Wi) is It may have an impact on several types of environmental effects (C_k) (its impact value is I_{ik}). Different emissions have different degrees of impact on certain environmental effects. If emissions Wi are used as the reference emissions for evaluating C_k environmental effects, then the effect of W_i on C_k can be made the relative weight of environmental impact relative to Wes to Ck is β ik. At the same time, assuming that the quantified value of W_i is Qc_i, the unit environmental impact A_k of the emissions on a certain environmental effect (C_k) is

$$A_k = \sum_{i=1}^{n} I_{ik} (10)$$

$$I_{ik} = \beta_{ik} Q_i (11)$$

$$Qci = e_i dp (12),$$

where e_i equals to the air emissions per ton-kilometer, and dp is the collection-transportation distance.

Different environmental effects have different impacts on ecology and the environment. In order to improve the objectivity of the analysis results, the weighting factor of different environmental effects can be *sk*, then the environmental impact value (EI_j) of the unit process (Prj) can be expressed as

$$EI_j = A_k s_k (13)$$

For the total process, the unit environmental impact index should be

$$EItp = \sum_{j=1}^{t} EI_j (14)$$

2.5.2 Estimation of EI

The MSW needs to be optimized considering the environmental impact as well. The least polluting waste transfer procedure must be obtained for transfer. The main impact on the environmental is not only due to the emission on hazard air and GHGs from transportation vehicles but also in processing the waste in the transfer stations.

Environmental impact index (EI) $= \sum_{p=1}^{m} MpEI_{tp} (15)$,

where EItp represents the total value of environmental index of point p to collection and transport the waste.

2.6 Constraints on solid waste optimization

The constraints are the restrictive conditions that need to be considered in any given situation.

1. Mass balance constraint

While designing a MSW model. A balance mass flow of waste in the entire MSW system needs to be maintained.

2. Capacity constraint

The operating capacity of a treatment facility depends on several factors including availability equipments, manpower, etc. the waste reaching at a facility must be less than or equal to its capacity.

3. Demand constraint

The main target of MSWM is to meet the demands of the customers. All efforts to optimize collection and transportation will be in vain if this demand is not fulfilled.

4. Regulatory constraint

Some regulatory constraints must be figured out while formulating the optimization objectives in MSW system. In this study, the total number of transfer stations will be built is restricted by the local government

5. Binary constraint

The binary constraint is normally considered for decision variables. It assures that the decision variables are equal to or greater than zero. Binary constraints in the model ensure the inclusion capital of new transfer stations if started.

2.7 Trade space analysis of the sites

Firstly, filter all candidates to the sites matched all the policies and regulations. And then, take the qualitative analysis of pareto optimal solutions. In this case, given an inherent group of transfer station candidates and an allocatable resource of environmental impact performance and economic performance. Finally, the decision will be made by the municipal level. Trades of all the candidate sites configuration/combination are to identify pareto-optimal design solutions. Include political or social limitations. Commonly, there will be some designs meet the requirements in the construction standard. Otherwise, there will be a construction upper limit on the number of transfer stations from the agency of construction and management according to the land use plan, the total construction budget, and the population size of the area where the station is planned to be built.

3 Case Study

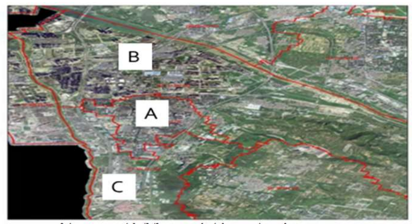

Figure 2 Map of the study area

Taking the current rates of municipal solid waste generation in 3 subdistricts as the study area, which locate in the east of Xi'an city, which is the largest city in Shaanxi Province, China. The whole city plans to build about 60 transfer stations and 5 incinerators as the final MSW disposal plants to complete the construction of the municipal solid waste management system. However, the work is not going well by currently empirical site selection method. And the residents have strong resistance to the construction of waste transfer station. Because the difference in cost composition for subdistrict A (the built-up area) without the existing TSs and subdistrict B and C (the starting area) with 5 TSs. I analyzed the study area into two parts.

Figure 3 the built-up area

3.2 results of site selection in the built-up area without TSs

The construction of a new waste station is the most urgent task for A sub district since there is not a station operated. There is no doubt that the indirect cost is fairly greater than direct cost. From the figure 3, there are 5 candidates that meet the requirements and have sufficient land supply, they are station S1, S2, S3, S4, S5 as shown in the following figure, respectively.

There are 2^5 =32 designs on the sites of transfer station selection in Sub District A under the tradeoff between total cost and environmental impact. Where the lowest cost appears in Design 32 of 0, because in that design there is no transfer station built in A subdistrict. Comparably, the total environmental impact index is the largest. Whereas the lowest total environmental impact locates in Design 1 of 1.11E+02Pt. In this design,

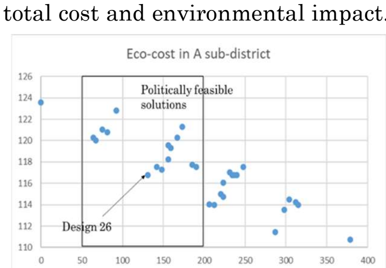

Figure 4 32 Designs of the built-up area the stations could be built at S1, S2, S3, S4, S5. However, the sub district wishes to build no more than 2 stations, therefore, this design is impractical. Design 26 of the total cost is 131 units and total EI is 1.17E+02 meets the requirements both in regulations and municipal plan, which is one of the pareto optimal solutions.

Table 1 Design 26 with 2 transfer stations

Design 26						
Community covered	1-7	1-7	1-7	1-7	1-7	Total
Candidates	S1	S2	S3	S4	S5	
Build	0	0	0	1	1	2
Cost	0	0	0	67	64	131
EI	2.49 E+01	2.39 E+01	3.21 E+01	1.74 E+01	1.86 E+01	1.17 E+02

However, On July 7th of 2021, I dialed with the person in charge about the feasibility of my result. I was noticed that, with the consideration of capital cost and social acceptance cost, the investment amount has far exceeded the budget in my proposal since they pay more attention on the overall cost rather than environmental impact to carry out the construction plan. In this case, one of the pareto optimal solutions changed into Design 27, which build a new transfer station of S5 in figure.

Table 2 Design 27 with 1 station

Design 27						Total
Candidates	S1	S2	S3	S4	S5	
Build	0	0	0	0	1	1
Cost	0	0	0	0	64	64
EI	2.49E +01	2.39E +01	3.21E +01	2.09E +01	1.86E +01	1.20E +02

3.2 Result of site selection in the starting area with 5 stations

Figure 5 the starting area

There are 32 designs for Subdistrict B and subdistrict C as well. The results are shown in the following table A.2. The lowest cost appeared in the design 32 of 95 and 1.64E +02 Pt for the result of total environmental impact, where the waste transfer stations will be built at S6 and S7, which does not meet the regulative requirement. The one of Pareto optimal solutions appears in Design 20 with the overall cost of 102 and EI of 1.62E +02 Pt, in this design the transfer station will be built at S6 and S9.

Table 3 Design 20 with S6 and S9

Design 20						
Candidates	S6	S7	S8	S9	S10	
Build	1	0	0	1	0	2
Cost	50	0	0	52	0	102
EI	2.23E +01	2.39E +01	3.21E +01	1.74E +01	2.19E +01	1.62E +02

3.3 Overall optimization for the study area

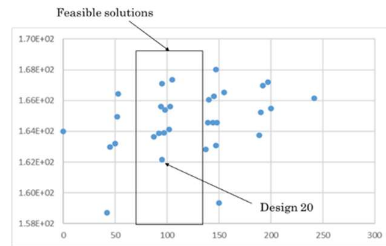

Figure 6 Designs of the starting area

In this section, the regulative constraint will not to be taken into account. Which means, the study area will be regard as a whole. And then, There are 1024 designs to find the Pareto optimal site selection. One of the pareto optimal result appeared in Design 948 with total cost of 161 units and the total EI is 2.19e+02. The Stations should be built at candidate S6, S8 and S10. In this case, there will be not any stations built in the built-up area. Which seems impractical.

4 Conclusion and Discussion

By this study, a multi-objective optimization model for the optimal location on site selection of the MSW transfer station with fully consideration of the factors about environmental impact, cost optimization and social acceptance has been proposed. The study can aid decision makers to locate the optimal sites of municipal solid waste transfer stations under the trade-off between cost and environmental influence of waste collection and transportation via waste transfer stations. The semi-structured interview provides a realistic meaning to form the objective functions to make the multi objective optimization more practical. By considering environmental protect and sustainability in the field, the study uses LCA to evaluate the environmental impact for the site selection of MSW transfer station. As a case study-oriented research, the conventional solution approaches of the optimization make the problem less complex to be solved. Through applying the conventional approach and the generation of pareto optimal solutions to optimize the total cost and the total environmental impact index for the construction of the MSW transfer stations. However, because the research is case-study oriented, it does not require much calculation. The conventional solution approaches of the MILP has shortcomings in terms of large computational efforts and risk of high dimensionality. Additionally, different life cycle assessment methods have their own weighting method which remains a controversial issue. Moreover, transform a social problem to the cost problem is subjective, therefore, economic factors cannot be used as the only means to solve the NIMBY problem.

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