

Economic Model for Household Solid Waste Collection

Mustafa Elkhedr
Assistant Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Giza, 12316, Egypt
E-mail: melkhedr@eng.cu.edu.eg

Abstract

Protection of public health and water resources is partly maintained through efficient waste collection. This paper presents a model to calculate collection and transfer cost of household solid waste. The model was applied to estimate the collection and transfer cost of household waste for a district in Cairo, Egypt. The model was calibrated and verified using data that was collected through surveying 30 waste collectors. The model is applied for both new and used trucks and is successful in determining the required fee to be collected per household and per ton of waste. The collection and transfer cost model is based on variable and fixed costs. Collection and transfer costs, in Egypt, were less than those presented in literature. This was attributed to lower labour cost and lower capital costs needed for waste collection and transfer.

Keywords: Municipal solid waste management system; Collection and transfer cost; Household Waste, Waste collection model

1. Introduction

Cost components of Municipal Solid Waste (MSW) management system depend on location, household income, waste characterization, waste quantity, methods of processing, treatment and disposal, collection and transport, distances travelled, and labour wages. The cost component related to the collection and transport of waste is a significant portion, which may reach 60-70% of the total cost. The waste collection, transfer and transport phase is a complex component of the system, involving the municipalities, collectors, and the households. A large portion of the system cost is allocated for this component (Laureri et al. 2015). Improvement in this component is essential to prevent uncontrolled and random dumping which would negatively impact the environment. Thorough planning for this component is essential for the efficient and effective use of resources and costs. The collection and transfer cost is affected mainly by the method of transport of waste, the type of wastes, and the quantity (EPA 2002).

Many countries in North America and Europe have regulations on the vehicle types and sizes used, permissible routes, and hours to operate for waste collection and transfer. Safety requirements are also in place to provide effective service and prevent potential harm to the public (EPA 2002). Waste collection and transfer is efficient when performed with the least required labour and cost and the least time of contact with waste. This requires good management of the MSW system and the involvement of all stakeholders including municipalities, collection companies, and public.

The cost and effort required for collection and transfer of waste depends on many factors including the type and quantity of waste being collected, the number of collection points (e.g. number of households), and type or method of waste collection. The unit cost of waste collection increases proportionally with the increase of amount and frequency of waste collection. Several factors lead to inefficient management of the collection and transfer component. This would include unsuitable types or size of vehicles, inadequate number of labour or shifts, poor maintenance of vehicles, long distances to dump sites, and busy traffic routes due to inappropriate collection hours (UNEP 2008)

The main objective of this paper is to present an economic model encompassing the factors that affect the cost of collection and transfer of household waste. A case study is presented for collection and transfer of household waste for both new and used trucks.

The remainder of the paper is structured as follows: Section 2 briefly overviews the waste collection and transfer component in Egypt. Section 3 presents the objective of the paper and data collection process. Section 4 provides the model formulation. Section 5 presents the results of applying the model that calculate the collection and transfer cost of waste. The paper ends with conclusions of the main findings in Section 6.

2. Background

The cost of providing waste collection service varies and is generally highly dependent on the method of collection, the quality of service, and the location of service (Stevens 1978). Generally, it is found that private companies collect and transfer waste at lower costs than the public sector. Young (1972) argued that this could be due to the larger scale of economies and greater efficiency and effectiveness of the private sector.

There is extensive literature on waste collection costs using different models that take into account labour wages, vehicle costs, and emission costs among other factors. Groot et al. (2014) developed a comprehensive waste collection cost model to compare costs of different collection methods of post-consumer plastic packaging waste whether recycling through source-separation or post-separation. Bel and Fageda (2010) developed a model to determine solid waste costs. They took into account the frequency of waste collection, waste generation rates, and average salaries of waste collectors.

Larsen et al. (2010) developed a model for calculating the cost of glass and paper recycling in Denmark. The model considered the cost of collection equipment, actual collection costs and treatment costs. Beigl and Salhofer (2004) calculated waste transport costs for a regional waste management company in Austria. Life cycle assessment models were developed for different cases of waste collection with and without waste separation and recycling. Cruz et al. (2012) developed a model that considered operational cost of collection and sorting as well as the depreciation of assets.

Fiorucci et al. (2003) developed a decision support system, to determine the optimal number of landfills and treatment plans required for a municipality. The model considered recycling, transport, and maintenance costs. They considered the transportation cost of waste including the number of employee required, vehicle related costs, and any possible tolls required. Jacobsen et al. (2013) compared between the private and public sectors collection costs of municipal waste in Belgium. It was found that the private sector incurs less cost than the public sector.

Waste collection in Egypt is completed through private waste collectors hired by large public or multinational waste collection companies. These companies are contracted through the local municipalities. The private waste collectors collect waste from apartments at a cost of a monthly fee paid by apartments. The waste is collected without separation or recycling. Although small initiatives are present in several areas, they are not considered widely applied to be considered for analysis. The waste is then transferred using light open trucks and dumped at specified transfer stations, where the large companies collect from these points to sorting and composting facilities or landfill sites using larger trucks (SWEEP-NET 2014).

A report by the UNEP (2008) found that the collection cost was in the range of 15 to 40 US$/ton for low income areas, 25 to 75 US$/ton for middle income areas, and 75 to 150 US$/ton for high income areas. Accordingly, the collection cost was in the range of 2 to 4 US$/ capita/ year for low income areas, 5 to 14 US$/ capita/ year for middle income areas, and 55 to 110 US$/ capita/ year for high income areas. Low income areas are considered areas with an income of 500 US$/capita/year, middle income are for areas with an income of 3,000 US$/capita/year, and high income are considered areas with an income of 25,000 US$/capita/year. The average income is based on selected world development indicators from the World Development Report 2000/2001. These values will be compared to the results of this study.

3. Research Objective

The objective of this paper is to develop an economic model that describe and estimate the cost component of collection and transfer of waste. Determining the actual cost of MSW management components is necessary to set a fair pricing system for waste generators and service providers to feed into a waste management masterplan. Regarding waste collection, this will enable optimize the cost and efficiently collect and transfer the waste.

Research in this area in Egypt is somewhat new and much information is lacking. Data such as salaries, office equipment/expenses, vehicles used, transfer distances would be needed. Many companies do not, however, keep a record of the volumes of waste collected, number of trips, or fuel and maintenance costs.

4. Methodology

To perform this research, first, data is needed including information on the collection companies in terms of labour, vehicles and tools, the system of waste collection, and the waste characterization. Based on this information, an economic model is developed.

4.1 Waste Collector Information

In this research, the model was formulated based on cost-breakdown collected from 30 waste collectors in Egypt. The reason 30 companies were chosen was to produce reliable results to feed into the waste collection model. A sample of at least 30 would ensure normal distribution of results. The following information was requested from waste collectors:

- Capital cost of assets including vehicles purchased
- Condition of truck (purchased new/old)
- Equipment costs including gloves, aprons, boots, etc.
- Depreciation rate of assets
- Salaries paid to drivers and collectors
- Fuel costs
- Vehicle repair and maintenance costs
- Tire costs
- Average number of trips to a transfer station per day
- Average number of apartments served per trip
- Average length of round trip to a transfer station
- Average truck capacity

Using this data, analysis was performed to determine the following:

- Annual cost of assets
- Annual operational costs
- Annual costs are divided by waste tonnage to determine the unit cost of waste

4.2 Household Waste Generation

The SWEEP-NET report (2014) found that the household waste generation rate was 0.7 -1.0 kg/capita/day in urban areas and 0.4 – 0.5 kg/capita/day in rural areas. Elkhedr (2016) performed a waste characterization study and found the annual average generation rate per capita was 0.65 kg/capita/day. The average household occupancy in 2015 as per the Central Agency for Public Mobilization and Statistics (CAPMAS 2015) was 4.0. Therefore, the average annual waste generation per household was 2.6 kg/day.

4.3 Model Development

The total collection and transfer costs ($C_{veh_{tot}}$) take into account costs related to the vehicle cost and labour cost. All calculations are based on annual values and per kilogram of waste collected.

4.3.1 Vehicle Fixed Costs

Vehicle costs include fixed and variable costs. These costs were found to depend on two main factors including the condition of the transportation facility (new or used) and the transfer time. Annual fixed vehicle costs ($C_{veh_{fixed}}$) are the sum of the annual capital cost($C_{veh_{cap}}$), insurance cost ($C_{veh_{ins}}$), and tax cost ($C_{veh_{tax}}$) as per Eq.1.

$$C_{veh_{fixed}} = C_{veh_{cap}} + C_{veh_{ins}} + C_{veh_{tax}} \quad (1)$$

The insurance and tax costs have fixed annual values. The annual vehicle capital cost ($C_{veh_{cap}}$) is determined economically using the equivalent annual worth equations given the initial purchase value ($C_{veh_{pur}}$), salvage value ($C_{veh_{salv}}$), interest rate (*i*), and depreciation period (*n*) as shown in the equation below:

$$C_{veh_{cap}} = C_{veh_{pur}} \ (A/P, i\%, n) - C_{veh_{salv}} \ (A/F, i\%, n) \quad (2)$$

Where *A* is the annual uniform value of purchase price and salvation value of the vehicle, *P* is the present value of purchase price and *F* is the future value of salvage cost of vehicle.

This equation could be summarized as follows:

$$C_{veh_{cap}} = [C_{veh_{pur}}(1+i)^n - C_{veh_{salv}}] * \frac{i}{(1+i)^n - 1} \quad (3)$$

4.3.2 Vehicle Variable Costs

Annual variable vehicle costs ($C_{veh_{var}}$) are the sum of the annual fuel cost ($C_{veh_{fuel}}$), tire costs($C_{veh_{tire}}$), and maintenance cost ($C_{veh_{main}}$) (Eq.4). The fuel cost depends on whether the truck is collecting waste between households or travelling back to the transfer station. Speeds in both cases are different, and therefore fuel consumption varies. Therefore, the total annual cost of fuel is equal to the price of fuel per litre of consumption (P_{fuel}) multiplied by the fuel consumption. The fuel consumption depends on the type of trip, whether collecting waste between households or travelling back to the transfer station. Therefore, the total fuel consumption equals to the sum of fuel consumption while driving during collection (FC_{coll}) by the total distance travelled during collection (D_{coll}) and the fuel consumption while hauling (FC_{haul}) by the total distance travelled during hauling (D_{haul}) as presented in Eq. (5).

$$C_{veh_{var}} = C_{veh_{fuel}} + C_{veh_{main}} + C_{veh_{tire}} \quad (4)$$

$$C_{veh_{fuel}} = (FC_{coll} \times D_{coll} + FC_{haul} \times D_{haul}) \times P_{fuel} \quad (5)$$

Annual tire and maintenance costs depend on the annual distance travelled and are considered a cost per kilometre.

4.3.3 Labour, Tool, and Overhead Costs

The cost of labour (C_{lab}) includes annual salaries paid to the driver and collectors as shown in Eq. 6. The cost of tools (C_{tool}) include miscellaneous equipment used in collection such as gloves, aprons, and boots. Overhead costs (C_{OH}) are considered per labour.

$$C_{lab} = S_{driver} + S_{coll} \quad (6)$$

Therefore, the final economic model for waste collection and transfer is as follows:

$$C_{WasteColl} = C_{veh_{fixed}} + C_{veh_{var}} + C_{lab} + C_{tool} + C_{OH}$$

$$=[C_{veh_{pur}}(1+i)^n - C_{veh_{salv}}] * \frac{i}{(1+i)^n-1} + +C_{veh_{ins}} + C_{veh_{tax}}$$
$$+(FC_{coll} \times D_{coll} + FC_{haul} \times D_{haul}) \times P_{fuel} + C_{veh_{main}} + C_{veh_{tire}}$$
$$+S_{driver} + S_{coll} + C_{tool} + \ C_{OH} \quad (7)$$

5. Calculation of Collection and Transfer Costs

As mentioned earlier, for the purpose of this study, a survey was conducted where 30 waste collectors were interviewed. The results of the survey are shown below. The table presents the 90th percentile of survey results for both new trucks and used trucks cases.

Table 1. Survey Results

Parameter	Abbreviation	Unit	New Truck	Used Truck
Annual vehicle insurance cost	$C_{veh_{ins}}$	EGP	12000	8000
Annual vehicle tax cost	$C_{veh_{tax}}$	EGP	5000	3000
Purchase cost of vehicle	$C_{veh_{pur}}$	EGP	250,000	150,000
Salvage cost of vehicle	$C_{veh_{salv}}$	EGP	150,000	80,000
Depreciation duration of vehicle	n	years	5	5
Interest rate of investment	i	%	10	10
Annual vehicle capital cost (Eq. 3)	$C_{veh_{cap}}$	EGP	41380	26466
Annual maintenance cost for vehicle	$C_{veh_{main}}$	EGP	5748.75	5748.75
Annual tire cost of vehicle	$C_{veh_{tire}}$	EGP	4599	4599
Fuel consumption during collection	FC_{coll}	l/km	0.2	0.25
Fuel consumption during hauling	FC_{haul}	l/km	0.15	0.2
Average collection distance	D_{coll}	km	15	15
Average haul distance	D_{haul}	km	90	90
Price of fuel/litre	P_{fuel}	EGP/litre	2	2
Annual fuel cost (Eq. 5)	$C_{veh_{fuel}}$	EGP	12,045	15,878
Annual driver salary	S_{driver}	EGP	24,000	24,000
Annual collector salary	S_{coll}	EGP	162,000	162,000
Annual fixed vehicle cost (Eq. 1)	$C_{veh_{fixed}}$	EGP	58,380	37,466
Annual variable vehicle cost (Eq. 4)	$C_{veh_{var}}$	EGP	22,393	26,225
Annual labour cost (Eq. 6)	C_{lab}	EGP	186,000	186,000
Annual tools cost	C_{tool}	EGP	10,000	10,000
Annual overhead cost	C_{OH}	EGP	50,000	50,000
Annual total cost (Eq. 7)	$C_{WasteColl}$	EGP	326,772	309,691
Annual total cost per household	C_{total}/HH	EGP/HH	60.51	57.35

The following calculations were used:

- Trunk capacity of truck is 5 x 2.07 x 2 m^3 that can carry 2.25 ton per load which is approximately waste of 900 households.
- Depreciation period of truck is 5 years.
- Used truck is 5 years old.
- Annual maintenance cost for vehicles is calculated based on 1500 EGP/10,000 km
- Annual tire cost for vehicles is calculated based on 1500 EGP per tire, replaced every 50,000 km.

- Approximate collection and hauling distance of 30 km was based on enquiring the waste collectors and ranged from 10 km to 50 km, therefore, an average of 30 km was taken.
- Three trips are completed per day for a truck. Therefore, one truck serves 2700 households per day.
- Each waste collector collects waste from 300 households, therefore 3 waste collectors are required for each haul, and 9 workers per truck per day.
- Annual overhead cost is 5000 EGP per worker.
- Waste is collected from households once every 2 days. Therefore, one truck serves 5400 households.
- Annual average waste generation per household is 2.6 kg/HH/day.

Considering a percentage of profit of 20%, the annual fee/household would be 72.62 EGP or 6.05 EGP/month in case of using a new truck and 68.82 EGP or 5.74 EGP/month in case of using a used truck.

6. Analysis of Results

Since the truck collects waste from 2700 households per day, average annual household waste generation is approximately 0.949 ton. Therefore, the waste collection cost is 76.5 EGP/ton or 9.8 US$/ton (1 US$ = 7.83 EGP). These numbers were compared to literature. For example, in Istanbul, Doğan and Süleyman (2003) documented that the unit collection and transfer cost ranged between 12.2 US$/ton to 50.7 US$/ton with an average cost of 24.4 US$/ton in 2003. The result of this research is also compared to the values reported by the UNEP (2008), which found that the collection cost was in the range of 15 to 40 US$/ton for low income areas, 25 to 75 US$/ton for middle income areas, and 75 to 150 US$/ton for high income areas. Even high-income districts in Egypt are considered low-income when compared to the definition values of low-income in UNEP (2008).

The reason the collection and transfer cost is low in the sample taken could be attributed to several reasons. First, labour costs in Egypt are considered minimum compared to other countries, especially developed countries. Second, the capital costs including purchase price, salvage value, insurance, and taxes are much less than other regions. For example, the purchase price of a new truck was documented in Groot et al. (2014) as 206,000 Euros which is more than 2 million EGP. In addition, the insurance cost was taken as 2500 Euros/year, and the tax cost was taken as 1000 Euros/year. These values in Egypt are much less as demonstrated previously.

The capital cost of vehicle constitutes 18% of the total annual cost of waste collection and transfer for new trucks, and the labour cost constitutes 57%. For used trucks, the cost of labour is the major cost component (60%), followed by the capital cost (12%).

With some changes in the input parameters, different insights could be gained from the model which would help in decision support for future changes in prices. For example:

- Each 1 EGP increase in the fuel price would result in an increase of 1.84 % in the collection and transfer cost for new trucks and 2.56 % for used trucks.
- Each 10% increase in the insurance or tax cost would lead to an increase of 0.52% in the collection and transfer cost for new trucks and 0.36% increase for used trucks.
- Each 10% increase in the purchase price of the vehicle would lead to an increase of 2.13 % in the collection and transfer cost for new trucks and 1.28% increase for used trucks.
- Each 10% increase in driver and collector wages will lead to an increase of 5.78% in the collection and transfer cost for new trucks and 6.01% increase for used trucks.
- Each 10% increase in the collection and hauling distance will lead to an increase of 0.69% in the collection and transfer cost for new trucks and 0.85% increase for used trucks.

Therefore, collection and transfer costs are most sensitive to labour costs and changes in salary.

7. Conclusions

This paper presented an economic model to calculate the waste collection and transfer fee that can provide decision support to companies for analyzing costs and determining needs such as labour, number of vehicles required, and allocating costs of fuel and maintenance. It would also help in preparing budgets, finding deficiencies in the different cost elements, and comparing results between different districts. The model also investigated the impact of the different cost parameters and the effect of their change on the total collection cost and the final cost per household. Ultimately, this would lead to a better, more efficient and cost effective service.

For further research, the emissions involved in the waste collection and transfer process could be accounted for. The cost related to this component is environmental and could be considered financially. In this regard, several research has considered this aspect such as Tsiliyannis (1999), who considered the environmental impact of municipal solid waste management. Chang and Wang (1997) developed a model that considered noise impact, air pollution impact, and traffic congestion.

A comparison could be also made between different income level districts. Waste characterization is different between different income levels as well as the costs associated with the collection and transfer of waste. The work presented in this paper could be incorporated into route optimization models for waste collection to identify routes at lowest cost. For example, Kulcar (1996) developed a methodology to minimize transportation costs in urban areas. Nuortio et al. (2006) developed an approach to optimize vehicle routes and schedules to collect municipal solid waste in Finland.

Finally, a comparative analysis between the current state of waste collection and the cost associated with it could be performed to recommend improvements in the waste management system.

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