Cost Appraisal of Municipal Solid Waste Transfer to Disposal Site Using Visual Basic Program

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Abstract: Collection of Municipal Solid Waste (MSW) accounts for a significant proportion of most municipal budgets, and has drawn some degree of researchers' interest. This study was conducted in Ota, Southwest Nigeria, to explore the use of Visual basic program as an innovative tool to select the most economic haulage system among three systems found in literature (conventional-, modified- and Stationary- hauled system) for collection and transfer of MSW to disposal sites. Factors that affect the costs of collection and transportation of waste such as: vehicle cost, total time spent on waste collection, and gross travel cost, were considered in the analysis. The result of the study shows that the stationary hauled method of waste collection is the optimal and economical method of collection. This method recorded a 56% and 43% reduction in total cost of daily travel per waste collection, as compared to the conventional and the modified systems, respectively. The application of visual basic program proffers implementable solutions to reduce the cost of MSW transportation to disposal sites. This would reduce travel time and costs of vehicle fueling, and increase the prompt collection of waste which would in turn facilitate the development of an aesthetically balanced and environmentally friendly municipality that would perhaps boost economic development.

Keywords: environmental sustainability, haulage systems, municipal solid waste, optimal collection cost, visual basic.

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INTRODUCTION

The growing complexities in Municipal Solid Waste (MSW) management have necessitated the development and application of new tools. These complexities are seen in the form of waste composition and the ever-increasing per capita waste generation that poses a challenge to effective waste collection. Some of the challenges that characterize the ineffective management of MSW in developing countries are inefficient collection methods, insufficient coverage of the collection system and improper disposal of solid waste. Kyessi and Mwakalinga (2009) stated that rapid urbanization has increased the pressure on social services, most of which have not been sustainably provided to match socio-economic and demographic growth. Its consequence is evident in poor urban service delivery, including uncollected solid waste in many urban locations. Agunwamba (2003) and Olukanni (2013) stressed that most city council struggle to

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deal with domestic waste due to lack of a cohesive collection and disposal system, and frequent breakdown of waste collection trucks. Zurbrugg (2003) expressed that one to two thirds of generated solid waste in developing countries are not collected. Also, Agunwamba et al. (2003) and Nguyen and Wilson (2010) revealed that the cost of labor, purchase and maintenance of vehicles involved in the collection and disposal of solid wastes, have risen so high that many sanitation agencies are already finding it increasingly difficult to collect and dispose all wastes generated.

Primary collection of waste is one of the essential steps of solid waste management activity. This is necessary to ensure that waste stored at source is collected regularly and does not constitute environmental menace. Although households and institutions are often provided with waste collection bins for domestic refuse disposal, these collection bins, sometimes remain unattended to because of diverse transport problems (Chang and Wei, 2002; Olukanni et al., 2014). Ogwueleka (2009) stressed that the volume of solid waste being generated continues to increase at a rate faster than the ability of waste management agencies to improve on the financial and technical resources needed to parallel this growth. The cost of solid waste collection has been reported to form a large component of the final solid waste management cost (Chang and Wei, 2002; Agunwamba et al., 2003; Arebey et al., 2012; Olukanni et al., 2014). It was also noted in the study of Ogwueleka (2003), that in developing countries, local authorities spend 77-95% of their revenue on collection and the balance on disposal, but can only collect about 50-70% of municipal solid waste (MSW).

Several studies have been conducted on the development of a simple approach for solid waste collection and minimization of the collection cost (Huang et al., 2011;

Aremu et al., 2012; Nithya et al., 2012; Rada et al., 2013; Kao et al., 2013; Di Felice, 2014a; Teixeira et al., 2014). Among the several factors affecting collection costs are; quantity of solid waste generated, vehicle scheduling, fleet size, truck size, container combination, vehicle routing, and the location of transfer stations and disposal sites (Stessel, 1996; Ojiako and Nwosu, 1989; Chang and Wei, 2002; Agunwamba et al., 2003). This study emanated from the challenge with waste collection and the indiscriminate disposal of waste in Ota which is a concern to the local government waste management agency and the inhabitants. The study was therefore aimed at churning out a cost effective way of collecting and transporting MSW from source to disposal points. The specific objectives of this study are to: a) identify the main waste collection and disposal points in the study area, and b) utilize Visual Basic program as an innovative tool to select the best haulage system among three systems (conventional-, modified- and Stationary-hauled system) of MSW collection and transfer to disposal sites, as found in literature (Tchobanoglous et al., 1993; Agunwamba, 2001).

MATERIALS AND METHOD

Study Area

Ota is the capital of the Ado-Odo/Ota local government area and has the third largest concentration of industries in Nigeria (Salako, 1999). It is popularly referred to as the industrial hub of Ogun State. It covers an area of 878 square kilometers and lies between latitude 6°41′N and 6°68′N and longitude 3°41′E and 3°68′E. Ado-Odo/Ota Local Government has an estimated population of 527,242 (Male 261,523 and Female 265,719) (NPC, 2006). It also possesses a large market and an important road junction, found north of the Tollgate on the Lagos-Abeokuta expressway. Ota is also well known to be the location of the

"Canaan Land" Headquarters of the mega church Winner's Chapel, a place renowned for housing the world's largest single auditorium. Ota is gradually becoming a busy place because of its proximity to Lagosthereby increasing the migration of people into it (Olukanni and Akinyinka, 2012). The management of solid waste in Ota is the primary responsibility of the Ogun State Environmental Protection Agency (OGSEPA). Figure 1 shows the geographical location of Ota on the Nigeria map.

In a resolve to forestall sanitation issues, waste bins were provided by the local government and placed along the road side for ease of collection. Collection involves the removal of solid waste and transfer from the stored facilities directly to the disposal sites. The volume of each of the waste container provided by the local government waste management authority is 7 m^3 (Olukanni, 2013). These bins are used by residents as waste storage facilities. Figure 2 shows the waste collection bin at one of its location in the study area.

Fig. 1. Map of Nigeria showing the study area and adjacent cities to it

Fig. 2. One of the waste collection points

It was established that informal solid waste collection operations exist in parallel with official agencies in the municipality and solid waste collection are done spontaneously. This approach contributes to the high cost of solid waste collection. Waste are collected by residents and deposited in the storage container for the trucks to come and pick. Different types of vehicles such as: compactor trucks, mini trucks, tippers and open back trucks are the commonly used collection trucks to collect the waste. Preliminary investigation reveals that the few available trucks breakdown frequently due to overuse and most of the collection vehicles are in a state of disrepair. Figure 3 shows the example of the collection trucks in operation during a field survey. Crew size selection is largely influenced by the amount of waste per stop, number and location of collection points, type of storage containers, and hauls time to unloading and final disposal point.

Fig. 3. Compactor and the open trucks in operation during the field survey

Approach to the Study

Three known method of municipal waste transfer were evaluated in the study (conventional, modified- and Stationary-hauled system) (Agunwamba, 2001). Methods of data collection include: One-on-one interview with relevant authorities in the ministry of environment, with personnel responsible for waste collection and transfer to disposal sites. Dumpsites in the municipality were also visited in order to assess transportable routes that the waste vehicles ply to dispose waste. Random survey that involves interviewing people about how often the wastes at the key locations are collected was also carried out. A single type of truck, the medium-duty truck was considered during analysis for the three methods of collection systems.

This is the type that collects waste from the 7 m^3 bin from the source point to the disposal site.

Application of Visual Basic

Visual Basic is a high level programming language that evolved from the earlier DOS version called Beginners' All-purpose Symbolic Instruction Code (BASIC). The visual basic program is made up of many subprograms with each one having its own program codes that can be executed independently and at the same time, can be linked together (McDonald, 2009; Petroutsos, 2010; Zak, 2013). A design interface was developed to achieve a workable program application for the determination of the evaluation of collection and transportation cost of waste:

The first interface of the program was designed to calculate costs of waste collection and optimal mode of collection of waste. Provision for currency exchange rate was made while developing the coding and when a numerical input is declared, the program converts the declared numerical input into other currencies existing in the database of the program. Issues addressed in the forms created include: waste density and generation rates, population density, waste generated by residents, number of waste bins and average waste volume per bin, volume and mass of waste bin, carrying capacity and required number of trips by the collection vehicle.

Objectives for Program Development
i) Obtain quantity of waste generated by residents (kg/day);
ii) Obtain required number of collection trips per day to ensure an aesthetically balanced environment (optimal frequency of waste collection);
iii) Determine the gross cost of daily travel for waste collection and transportation using different collection methods;
iv) Determine total time required to complete waste collection considering factors of on-site timing, pick-up timing and off-route factors;
v) Obtain daily costs of labor (remuneration of waste workers);
vi) Determine efficiency, economical and operational costs of each of the modes of collection thus obtaining the best mode/method for waste collection and transportation.

Forms Developed in the Program
i) 'frm.wastegeneration': This form considers the quantity of waste generated
ii) 'frmtravelcosts' takes into consideration different travel relationships and determine the cost of travel of each trip taking different routes into consideration. The affected trips include: Station-source relationship; Source- source relationship; Source-destination relationship; Destination-source relationship; and Destination-station relationship.
iii) "frmtotaltime": when calculating/ estimating the cost of collecting and transporting waste, the time spent during the collection process is important to the progress of the collection process.
iv) "frmtcostofworkday": considers total cost of work per day.

Relationships amongst the Labels

$$\textit{Waste generated by residents} = \left(\frac{kg}{day}\right)\textit{waste generation rate}\left(\frac{kg/h}{day}\right)\times \textit{population density}\ (h) \tag{1}$$

$$\textit{Average quantity of waste per bin}\left(\frac{kg}{day}\right) = \frac{\left(waste..generation.by..residents\left(\frac{kg}{day}\right)\right)}{number\,of\,waste\,bins} \tag{2}$$

$$\textit{Mass of waste bin}\ (kg) = \left(waste.density\left(\frac{kg}{m^3}\right)\right)\times \\ volume.of.waste.bin\left(m^3\right) \tag{3}$$

$$\textit{The weight of the waste bin in tonnes} \\ \frac{(weight\,of\,bin.(kg)\times 10)}{1000} \tag{4}$$

$$\textit{Required number of trips} \\ \left(\frac{trips}{day}\right) = \frac{\left(weight.of.waste.bin..(tonnes)\right)}{carrying.capacity.of.vehicle..(tonnes)} \tag{5}$$

$$\textit{Distance travelled daily}\ (km) = \\ speed\ of\ vehicle\ (km/hr)\ \times\ time\ of\ travel\ (hr) \tag{6}$$

$$\textit{Cost of travel per trip} = \\ distance\ travelled\ (km)\ \times\ cost\ of\ fuel\ per\ km\ of\ travel \tag{7}$$

The size of the collection crew depends on the size and type of collection vehicle used, space between the houses, waste generation rate and collection frequency. Consequently, increase in the waste generation rate and

quantity of wastes collected per stop results in a bigger crew size.

MODELED COLLECTION SYSTEMS

Conventional Hauled Container System

Figure 4 shows the operation for the conventional hauled container system. In this method, the collection truck picks up the filled container of waste from the source point and moves straight to the disposal site, and then returns the emptied container back to its original point of collection.

This implies that; for every waste collection trip made from a service point, there is a trip back to that same source. However, it can be observed from Figure 4 that there are connectors between the waste sources. These connectors represent the source-source relationships amongst the waste collection points. This means that after the waste has been emptied at the destination point and the empty bin has been returned to the source point, the waste collection vehicle moves to the next waste source to be collected. Therefore, the general expression for the conventional hauled container system to determine its total cost was developed as:

$$Total\ cost\ of\ travel = p.s + \left(n \times \left(s.d + d.s \right) \right) + \left((n-1) \times s.s \right) + d.p \tag{8}$$

where:

p.s = cost of travel from parking station to source point

n = number of waste collection trips made

s.d = cost of travel from source to destination

d.s = cost of travel from destination to source

s.s = cost of travel from source to source

d.p = cost of travel from destination to parking station.

Modified Hauled Container System

Figure 5 shows the modified hauled container system. In this method of collection, the collection crew sets out of the station with an empty bin and at the first station, the bin is dropped off while the filled bin at the site is collected and taken to the disposal point. The filled waste bin whose content has been disposed from the previous site, is then taken to the next source and dropped off as the new empty bin for that source. Then, the filled bin on site is taken for disposal and then dropped off at the next source. This loop continues for as many sources as there are in the collection plan.
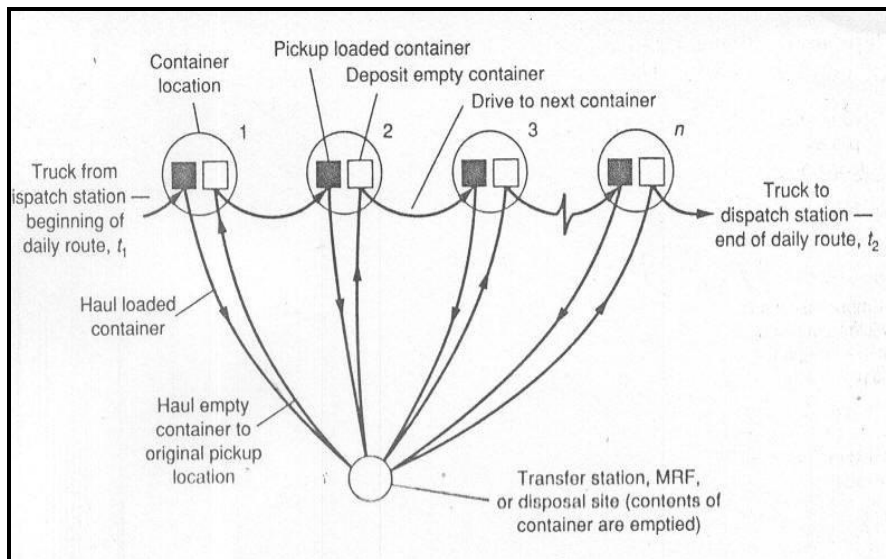

Fig. 4. Operational sequences for Conventional Hauled Container System.

Source: Adapted from Tchobanoglous et al., 1993; Agunwamba, 2001 (p. 307)
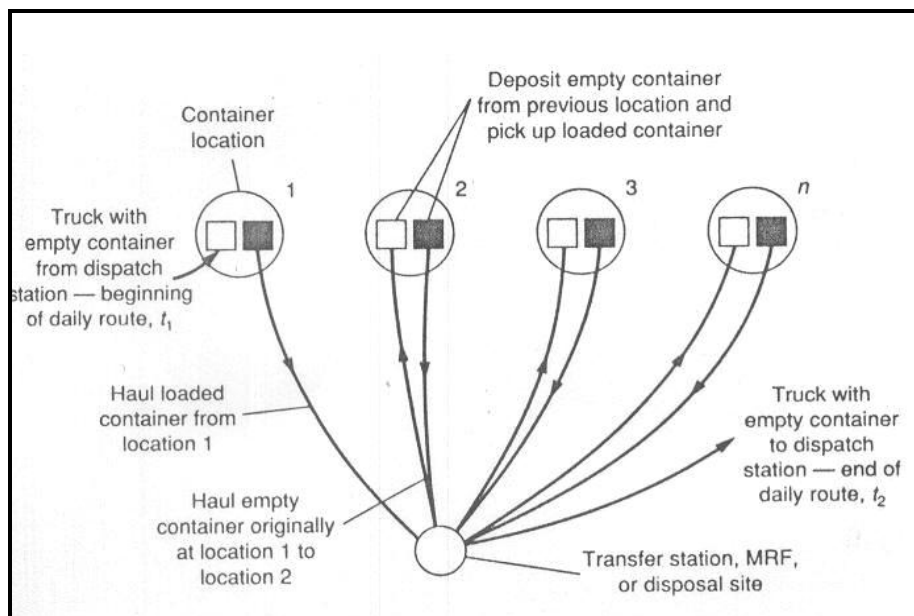
Fig. 5. Operational sequence for modified hauled container system

Source: Adapted from Tchobanoglous et al., 1993; Agunwamba, 2001 (p. 307)

As shown in Figure 5, there are four downward arrows indicating source to destination trips, and three upward arrows indicating destination to source trips. Therefore, the mathematical expression for the total cost was developed as:

$$Total\ cost\ of\ travel = p.s + (n \times s.d) + ((n-1) \times d.s) + d.p \qquad (9)$$

where:

p.s = cost of travel from parking station to source point

n = number of waste collection trips made

s.d = cost of travel from source to destination

d.s = cost of travel from destination to source

d.p = cost of travel from destination to parking station.

Stationary Container Systems

Figure 6 shows the third mode of waste collection which is the stationary container system. It is characterized by continuous collection of waste from source to source until all the sources for which waste is to be collected from have been exhausted and the waste vehicle is ready to return to the disposal site. The vehicle is limited by capacity constraints; it may have to go to the disposal site when it is full to capacity.

Figure 6 shows the illustration of the collection process and the interface from one point to the other. This indicates four connectors joining the five waste sources. This implies that the collection vehicle leaves the station and heads to the first station where the waste workers empty the waste contained in the bin into the vehicle and replace the bin back to its original position (same site) then moves onto the next waste location and collects the waste there using the same process. This continues for as many waste locations as are indicated in the waste collection route.

$$Total\ cost\ of\ travel = p.s + s.d + ((n-1) \times s.s) + d.p \qquad (10)$$

where:

p.s = cost of travel from parking station to source point

n = number of waste collection trips made

s.d = cost of travel from source to destination

s.s = cost of travel from source to source

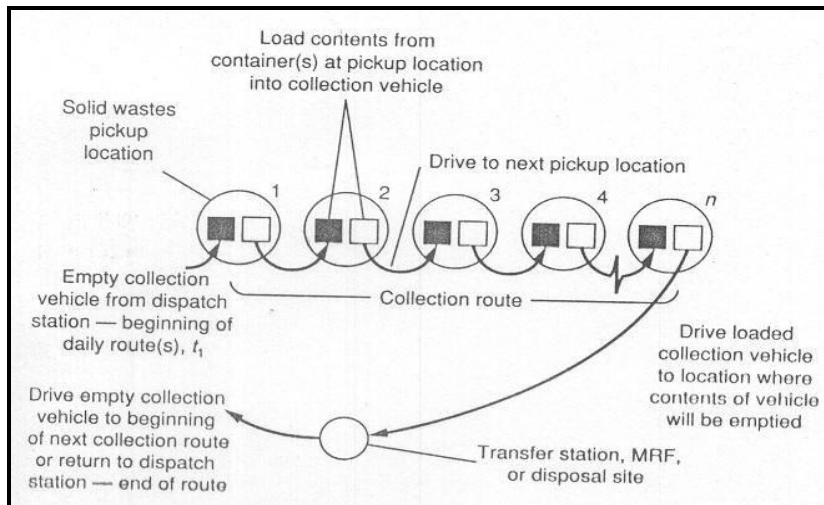d.p = cost of travel from destination to parking station.

Fig. 6. Operational sequence for stationary container system

Source: Adapted from Tchobanoglous et al., 1993; Agunwamba, 2001 (p. 307)

The values used for analyses for total time for collection were obtained from field study. In order to determine the optimal mode of waste collection in terms of cost efficiency, the same values of p.s, s.d, d.s, s.s, d.p and n were used to avoid discrepancies. The naira (₦) cost value, the Nigerian currency was considered in the analysis. Although, the exchange rate fluctuates, this is currently valued at an approximate rate of ₦200 and ₦240 to one dollar ($) and euro (€), respectively. The functionality button is used to define the most economical method of waste collection after calculations.

Determining the Pickup Time
This interface allows the calculation of the pick-up time (hr. /trip).

The pickup time P_{hcs} is expressed by

$$P_{hcs} = P_c + U_c + d_{bc} \qquad (11)$$

where P_c is the time required to pick up loaded container (h/trip); U_c is time required to unload empty container (h/trip), and d_{bc} is the time required to drive between containers. The last aspect in the interface addresses total time spent on collection per trip. The time required per trip for the hauled container system T_{hcs}, is

expressed in Equation 12 (Agunwamba, 2001, p. 308).

$$T_{hcs} = \frac{P_{hcs} + S + h}{1 - w} \qquad (12)$$

where P_{hcs} = Pick-up time; time spent driving to the next container after the empty container has been deposited plus the time spent picking up the loaded container plus the time required to redeposit the container after its content have been emptied, hr./trip

S = On-site time per trip, hr./trip

h = Haul time per trip, hr./trip

w = Off-route factor, expressed as fraction. It includes all the time spent on activities that are non-productive with respect to the actual collection.

The off-route factor (w) is represented by the label 'time spent unrelated to collection'.

The haul time per trip (h) is represented by the label 'travel time from source to destination'.

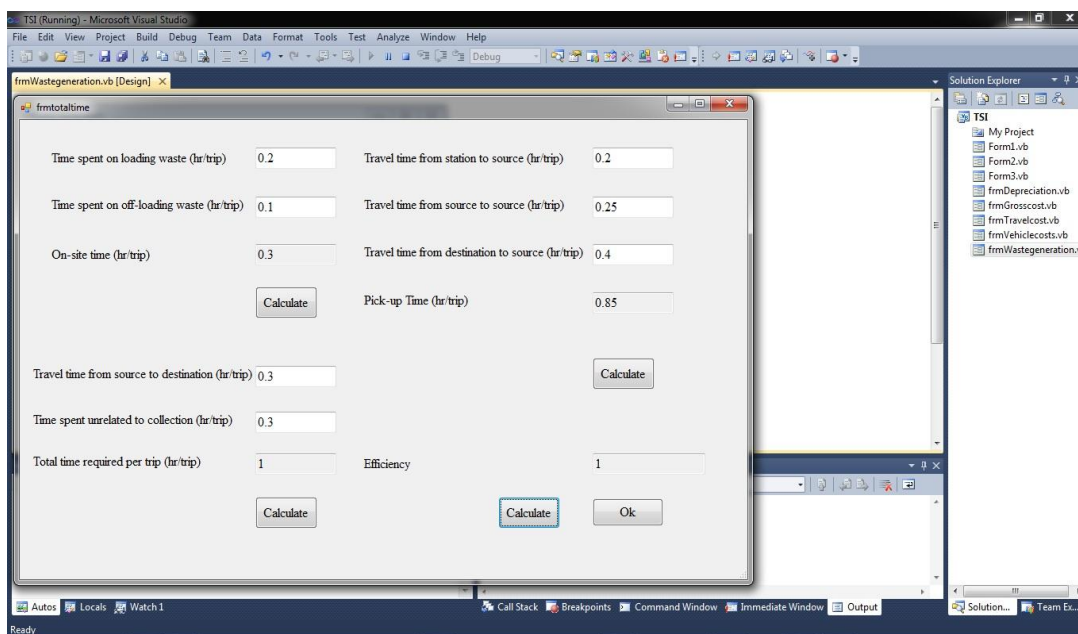Figure 7 shows the screenshot of the VB interface with the dialogue boxes for data input.

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Fig. 7. Screenshot of the VB showing Total time required for waste collection and transport

Program Interface (frmtcostofworkday)
This form is used to estimate the cost of the total collection process. This is achieved by first estimating the total length of an average workday (hr/day). An important aspect of solid waste collection and transportation cost analysis is labor. Labor cost is important in order to give a value for the amount of money to be spent on hiring labor for any of the three collection methods. Major factors that influence labor costs are; length of workday, time required per collection and disposal trip, number of daily trips, number of waste workers and remuneration per waste worker. After determining the length of a single workday, it is used alongside the money paid daily to the waste workers in order to determine the total cost of labor. Equations 13 and 14 show the relationships among all the listed factors required to obtain the daily cost of labor;

$$length..of..workday\left(\frac{hr}{day}\right) = time..required..per.trip\left(\frac{hr}{trp}\right) \times number..of..trips..daily\left(\frac{trips}{day}\right) \quad (13)$$

$$dcl = lwd \times nww \times rpww \quad (14)$$

where:
  dcl = daily cost of labour
  lwd = length of workday
  nww = number of waste workers
  rpww = remuneration per waste worker

The cost of fuel per km was obtained by determining the fuel consumption rate of the type of vehicle used for waste collection. The rear loader consumes 0.21 litres/km of travel. Thus, the amount of fuel consumed per km (x litres) is expressed mathematically as shown below:

$$x.litres = \frac{1.km \times 21.litres}{100km} = 0.21litres \quad (15)$$

Thus, the cost of fuel per kilometer is gotten by multiplying the amount of fuel required/km of travel by the cost of fuel per litre.

0.21 litres × ₦120/litre of fuel = ₦25.2 ($0.13 USD) per km of travel

However, a value of ₦30 ($0.15 USD) per km was used in the analysis (this is to cater for change in fuel price due to inflation and other economic parameters).

The speed and time of travel used in analysis were obtained empirically by personal trips to the various waste collection points. It should however be noted that some values are approximated by using a margin to cater for unforeseen conditions like traffic jam, condition of the road surface thus retarding travel speed and route selection.

RESULTS AND DISCUSSION

Solid waste collection vehicles are assigned to districts without any serious waste analysis. Route selection is left for drivers, and the vehicles are more than full on most trips to the disposal site. The collection in Ota is designed to be on a daily basis but unfortunately, the daily basis is not adhered to, which then causes indiscriminate disposal around the waste bin and individuals hipping up bags of waste along the road side. The collection system is also not efficient, this due to the inadequate collection vehicle. There is no house-to-house service and in most cases, people store their waste in bags and sacks by the road sides awaiting collection by the municipal authorities. The following findings were made after interviewing

necessary personnel in the State Ministry of Environment as well as some individuals amongst the waste workers:

i)   There are four trucks available for waste collection: two 26 ton trucks and 2 compactor trucks
ii) Maximum quantity of collectible waste per trip: 26 tons
iii) Number of waste personnel (refuse loaders) per truck was set at a minimum of 3 waste operators.
iv) Waste collection is not frequent
v)   There are 6 private waste managers, Private sector partnership (PSP) which is solely non-governmental.
vi) Monthly levy per household for PSP waste management is ₦1000 ($5 USD). However, the populace seems to disagree with this monthly fee as they presume it to be outrageous.
vii) The parking station for all waste disposal trucks is at Pan-mill in Ota.

   Figures 8 and 9 show the travel cost analysis and the optimal mode of collection. The waste generation rate for Ogun State is estimated at 0.6kg/capita/day (Ogwueleka, 2009; Olukanni and Akinyinka, 2012).
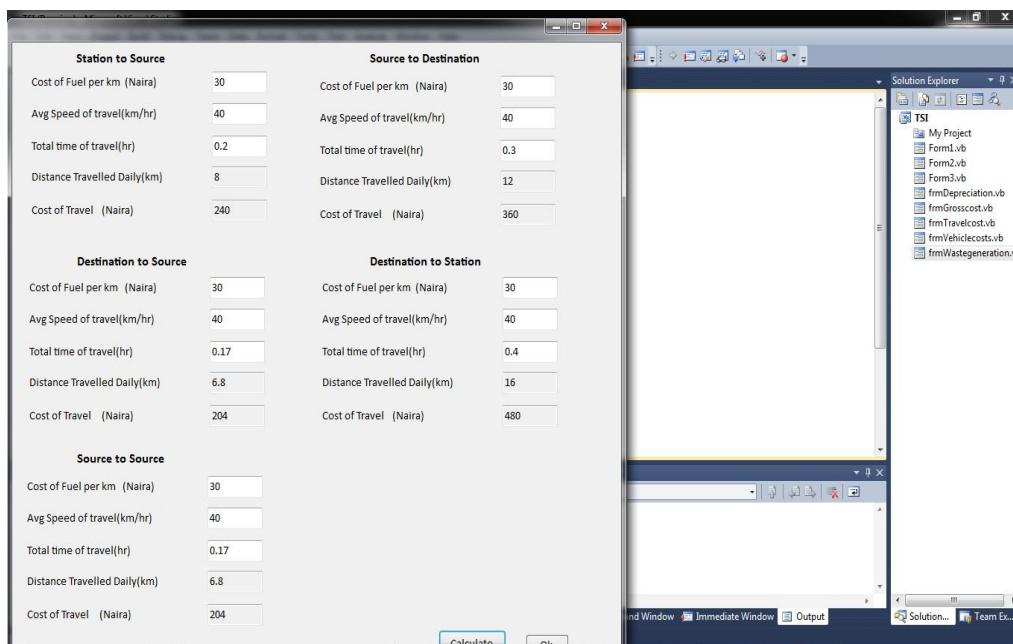

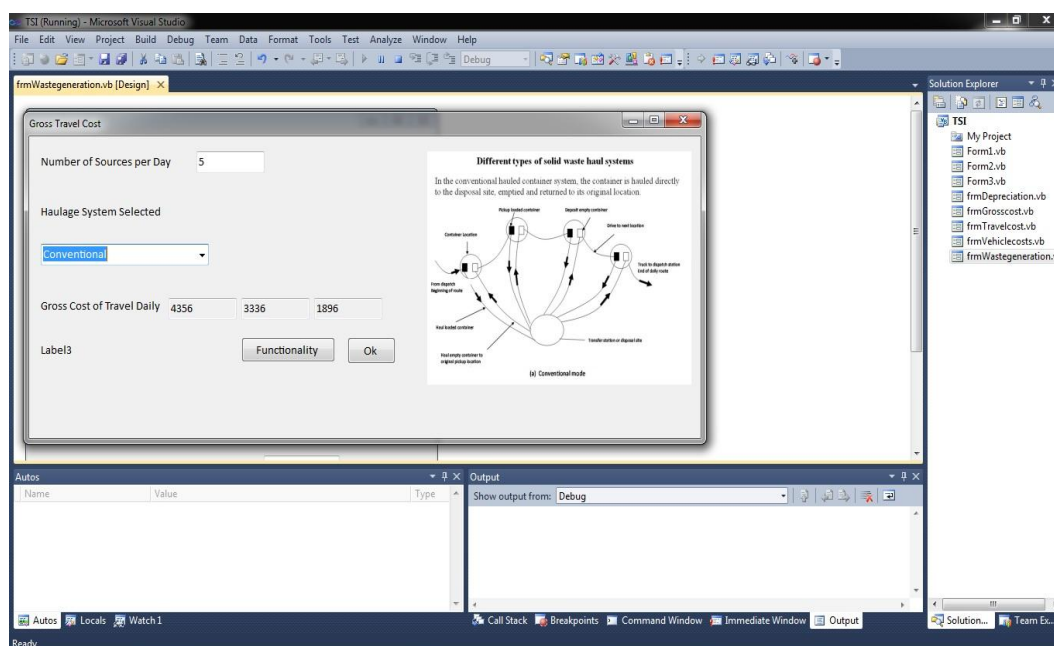**Fig. 8.** Screenshot of the VB interface showing Travel cost analysis

Fig. 9. Screenshot of the VB showing optimal mode of collection (Economic consideration)

Cost Comparisons

The Naira (₦) cost value, and the Nigerian currency were considered in cost estimation. This is valued at an approximated rate of ₦200 and ₦240 to one dollar ($) and euro (€), respectively. From the application of collected data in the analysis, the values obtained for total cost of daily travel per waste collection mode are:

Conventional: ₦ 4,356 daily ($22 USD)

Modified Hauled: ₦ 3,336 daily ($17 USD)

Stationary: ₦ 1,896 daily ($9.5 USD)

Therefore, the method with the lowest gross cost of daily collection of waste is the stationary hauled method. The result of the study shows that the stationary hauled method of waste collection is the optimal and economical method of collection with 56% and 43% reduction in gross cost of daily travel per waste collection, as compared to conventional and modified systems, respectively.

CONCLUSION

The scope and magnitude of waste collection may often exceed the budgetary capacity that local authorities have to put in place to effectively resolve issues of waste collection, transfer and disposal. The study however, proposes an optimal and efficient method of waste collection and transfer to the disposal site. The input parameters used in the model in estimating the total cost include the distance travelled from source point to disposal site, number of intersections and maneuvering during each collection trip. The result of the study shows that the stationary hauled method of waste collection is the optimal and most economical method of collection with 56% and 43% reduction in total cost of daily travel per waste collection, as compared to conventional and modified systems, respectively.

Having established the optimal model, cost savings arising from distance travel reduction, time and fuel consumption would mitigate the problems of collection and transportation costs when it is implemented. The results of the model can find useful application when planning an organized approach for MSW collection. The following measures are recommended in order to achieve sustainable solid waste management practice in the study area: i) Government should make adequate funds

available to waste management personnel for the purchase of more waste disposal containers and vehicles, as this would help in curbing the menace of roadside dumping, and ii) Waste collection should be regularly done provided there is adequate number of waste collection vehicles for disposal as this would be cost-effective, time-saving and would lead to an aesthetically sound environment.

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