CASE STUDIES

Technical aspects of municipal solid waste collection: case studies from East Africa

Mentore Vaccari and Francesco Vitali

PHOTO: Somaliland collectors. Francesco Vitali.

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EDITED BY
Global Dimension in Engineering Education

COORDINATED BY
Agustí Pérez-Foguet, Enric Velo, Pol Arranz, Ricard Giné and **Boris Lazzarini (***Universitat Politècnica de Catalunya)*
Manuel Sierra *(Universidad Politécnica de Madrid)*
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Katie Cresswell-Maynard *(Engineering Without Border UK)*

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TECHNICAL ASPECTS OF MUNICIPAL SOLID WASTE COLLECTION: CASE STUDIES FROM EAST AFRICA

Mentore Vaccari, assistant professor, CeTAmb LAB - Research Laboratory on Appropriate Technologies for Environmental Management in resource-limited Countries, DICATAM, University of Brescia.

Francesco Vitali, research fellowship, CeTAmb LAB - Research Laboratory on Appropriate Technologies for Environmental Management in resource-limited Countries, DICATAM, University of Brescia.

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1. INTRODUCTION

The present case study aims at presenting alternatives to improve the solid waste collection services in resource limited Countries. The contents of the case study were elaborated within the following projects in East Africa, implemented by the Italian NGO CESVI with the technical support of CeTAmb LAB - Research Laboratory on Appropriate Technologies for Environmental Management in resource-limited Countries of the University of Brescia:

- “Somalia Urban Development Programme (SUDP)” (2005-2008);
- “Support to Improved Service Delivery in Somali Cities (SISDISC)” (2009-2010);
- “Environmental protection and sustainable development: building local capacities on solid waste management in South Sudan” (2010-2012).

The approach and activities carried out by Cesvi and CeTAmb LAB - University of Brescia were aimed at priority basic services in the Solid Waste Management sector (Collivignarelli et al., 2011a, Collivignarelli et al., 2011b, Di Bella and Vaccari, 2014). In particular, the activities of CeTAmb LAB dealt with the technical aspects relating to appropriate technologies to be adopted in the collection, treatment, recycling and disposal of municipal solid waste.

1.1. DISCIPLINES COVERED

The main discipline covered in this case study is environmental engineering. The aim is to evaluate different waste management systems according to quantitative analysis and calculations but also on the basis of socio-cultural aspects. The trained students have to develop a problem-solving approach that takes into account not only the technical side but that leads to the choice of a solution which sounds appropriate for the local context and its peculiarities and constraints.

1.2. LEARNING OUTCOMES

The teaching material will present how to assess different solid waste management systems on the basis of data collected in the field or through experimental measuring activities. As a result of this case study, students are expected to be able to:

- Evaluate production and composition analysis as a basis to choose the most appropriate system;
- Assess different solid waste (primary and secondary) collection systems in terms of vehicles and staff.

1.3. Activities

The design of a municipal solid waste collection system is a complex task that needs a deep knowledge of the local context not only under a technical point of view but also under a social and cultural perspective. Local daily practice, habits, preferences and eventual taboos related to solid waste handling needs to be taken into account as well as institutional and geographical constraints and local regulation sectorial guidelines.

In the first activity (in classroom) the trainer will give the technical background, introducing the basics on solid waste (definitions, effects of inadequate management, main characteristics) and present the different solutions for collection with the numerical solution for one of them (2 hours). This activity may come with a field assessment with practical data collection for waste characterization (for example waste weighting in the school or waste density or composition assessment) (4 hours in groups).

Finally, students will be divided in groups (2-4 students per group) and a data set will be assigned to each group: in this activity (to be carried out at home) each group will study and propose an appropriate solution for the solid waste collection according to data and information given. A final report will be produced by each group for evaluation.

2. Defining the characteristics of solid waste

According to the WHO definition “Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and faeces. Inadequate sanitation is a major cause of disease world-wide and improving sanitation is known to have a significant beneficial impact on health both in households and across communities. The word 'sanitation' also refers to the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal. (WHO)”

2.1. Some definitions

Waste: an item that has become worthless to the initial user, and needs to be thrown away

Solid waste: all those wastes which are neither wastewater discharges nor atmospheric emissions. It can also be defined as any waste which is not liquid according to the extent of its flow and which needs to be removed from the surroundings.

Municipal solid waste: refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals; e.g., remains of food, office paper, etc.), market waste, yard waste and street sweepings

Municipal solid waste management: collection, transfer, treatment, recycling, resource recovery and disposal of solid waste

Integrated solid waste management: selection and application of sustainable technologies, and management system to achieve specific waste management objectives and goals. It is based on the concept that all aspects of a waste management system (technical and non-technical) should be analysed together, since they are in fact interrelated and developments in one area frequently affect practices or activities in another area.

2.2. PRINCIPLES

The principles of sustainable solid waste management are the following:

- minimization of waste generation and hazardousness;
- maximization of waste reuse and recycling;
- safe and environmentally correct collection and disposal of waste.

However, ensuring public health and safety is the prime reason for the existence of municipal solid waste management. In particular, the specific goals of solid waste management are:

- to protect environmental health;
- to promote the quality of urban surroundings;
- to support the efficiency and productivity of the economy;
- to generate employment and income.

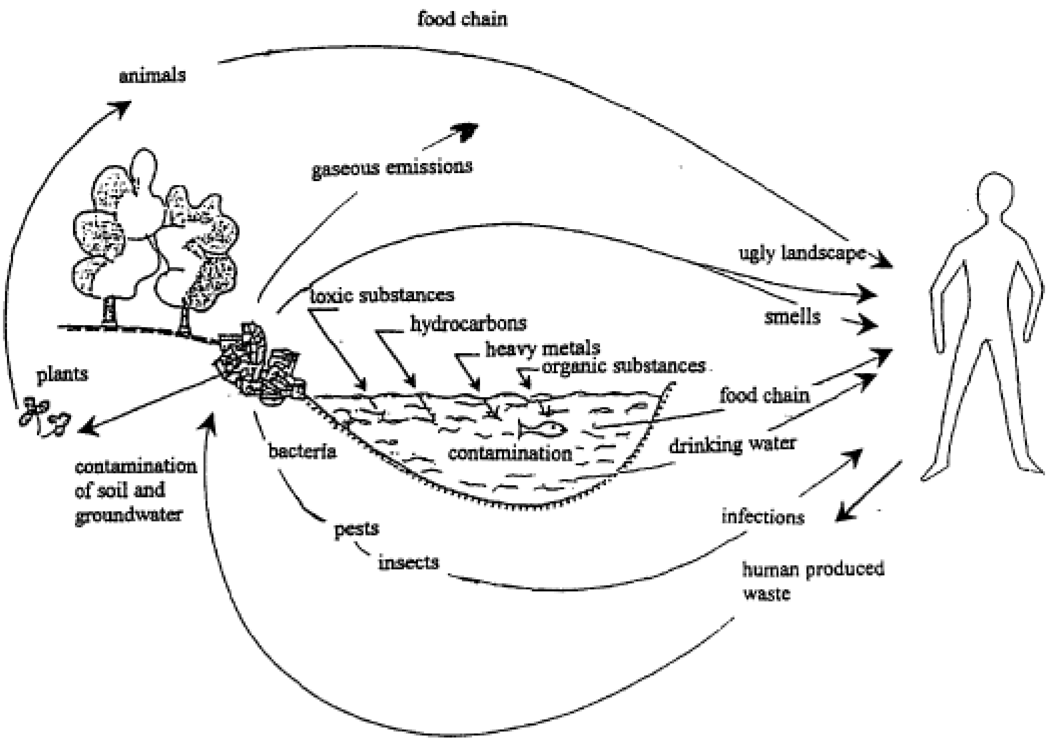
At the moment, in most African countries solid waste management is insufficient due to several reasons, such as inadequate means (skips, trucks) to collect and transport the waste, inappropriate landfills, lack of adequately trained personnel, or environmental education, absence of clear environmental policies, or authorities' control.

2.3. RISKS LINKED TO BAD MANAGEMENT OF WASTE

Poor solid waste management can pose serious risks to the health and safety of both the local population and the people who work with the waste. These risks, which are illustrated in Figure 2.1, include (WEDC, 2010):

- injuries and infection from direct contact with solid waste;
- the spread of disease by vectors: heaps of discarded waste provide a breeding ground for flies and rats;
- the spread of disease by other animals: foraging animals are likely to eat waste which may contain infectious diseases that are passed on when the meat is eaten;
- contaminated air: burning waste generates a large amount of smoke which can cause respiratory problems;
- accidents and injuries: traffic accidents and lifting injuries are frequent during the phases of collection and recycling;
- groundwater contamination: groundwater can become contaminated by polluted water from unsatisfactory disposal sites;
- fire and explosion: waste decomposition produces methane, which can support long-lasting fires and reach potentially explosive levels.

Figure 2. 1 *Routes of exposure to hazards caused by open dumping (Oeltzschner and Mutz, 1996)*



Some data:

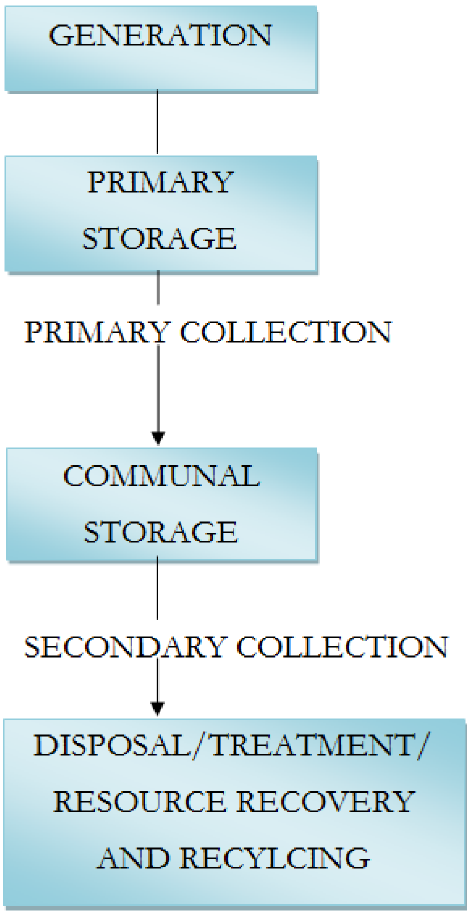
A survey conducted by UN-Habitat (2009) in several cities of the world shows significant increases in the incidence of sickness among children living in households where garbage is dumped or burned in the yard, compared to areas in the same cities where waste is collected regularly. Typical examples include:

- twice as high diarrhoea rates among children living in households where garbage is dumped or burned in the yard;
- six times higher prevalence of acute respiratory infections among children living in households where garbage is dumped or burned in the yard.

2.4. Stages in the solid waste management system

Hereafter the stages commonly involved in a system of solid waste management are reported. All the below stages may or may not exist in any single system of solid waste management. This depends on the size of the city, resources available and other local factors (WEDC, 2010).

Figure 2. 2 *Stages in the solid waste management system (Vaccari et al., 2011)*



Materials become valueless to owner. However, households sometimes segregate materials for re-sale.

Materials stored prior to collection.

First stage of collection, waste is transported to communal storage. (Sometimes waste is directly transported from primary storage to disposal.)

Optional but common in African countries. Waste is often stored after collection whilst waiting for further transportation.

Usually refer to collection in motorized vehicles. Waste is transported for final disposal.

Final destination of waste.

The most appropriate alternative for the collection, treatment and disposal of waste can be chosen only if the main characteristics of the waste (production, composition, density) are known. The following Table presents the average data for low income Countries.

Table 2. 1 *Typical characteristics of solid waste at collection point in low income Countries (Cointreau, 1982)*

Waste generated	0.4 – 0.6 kg/cap. & day
Waste density	250 –500 kg / m^3
Water content	40 – 80 %
Composition:	
- Organic	40-85 %
- Paper, Cardboard	1-10 %
- Glass & ceramics	1-10 %
- Metal	1-5 %
- Plastics	1-5 %
- Dust & ash	1-40 %

The above data are just a generic reference, but it is necessary to define the specific characteristics of the waste that has to be managed.

The following paragraphs illustrates synthetically which are the typical sources of waste in urban areas and how the main characteristics of MSW can be evaluated

2.5. TYPICAL SOURCES OF WASTE

HOUSEHOLD GARBAGE

This category comprises wastes that are the consequence of household activities. They proceed from food preparation, sweeping, cleaning, gardening wastes, old clothing, old furnishings, packaging and reading matter, faecal material (where bucket latrines are used).

Usually, the production of residential refuse varies from 0.3 to 0.6 kg/inh.*per day

Street sweepings

This category of waste always includes dirt and litter. However it may also contain appreciable amounts of household refuse, drain cleanings, human faecal matter and animal manure.

Usually, the production of street sweepings varies from 0.05 to 0.2 kg/inh.*per day

CONSTRUCTION AND DEMOLITION DEBRIS

Construction and demolition (C&D) debris consists of the materials generated during the construction, renovation, and demolition of buildings, roads, and bridges. C&D debris often contains bulky, heavy materials that include: concrete, wood, asphalt, gypsum, metals, bricks, glass, plastics, salvaged building components (doors, windows, etc.), trees, earth, rock, etc. from clearing sites.

The production and composition of this type of waste is site-specific.

SANITATION RESIDUES

Where sewerage is not the major means of managing human excreta and sludge, there are sanitation residues from latrines.

INDUSTRIAL WASTES

Industrial wastes come from processing and non-processing industries, as well as utilities: packaging materials, food wastes, spoiled metal, plastic and textiles, fuel burning residuals, and spent processing chemicals are among the wastes within this category.

The production and composition is site-specific, and depends on either the industrial processes, or natural resources or markets.

2.6. How to evaluate waste production

What is the daily waste production per person?

In order to assess the quantity of waste that requires collection and disposal, you have to select a sample area and measure the waste generated at household level.

Material needed:

- sample containers (eg, plastic bags),
- weighing scales,
- buckets,
- gloves,
- data sheets, marker pens.

Procedure

1. Collect the waste generated in the selected areas from houses once a day at a fixed time for 7 successive days to evaluate variation in waste generation in a week. The number of households to be selected depends on the size of the town.
2. Weigh the production of each household and record the weight in the data sheets according to the numbers of inhabitants per household. (kg/ house/day)
3. Finally remember to dispose all the waste properly and clean the equipment used.
4. Repeat 1. to 3. every day for the duration of the study.

Households	People per household	Days							Total (kg)
		Sat	Sun	Mon	Tue	Wed	Thu	Fri	
#1									
#2									
#3									
…									
Total	(A)								(B)

Computation

Daily generation rate = (B)/(A)/7 (kg/person/day)

2.7. How to evaluate the waste density

What is the weight of 1 m^3 of waste?

Waste density information when coupled with waste generation rates expressed by weight, allow the payload capacity of the collection equipment to be estimated. This kind of evaluation has to be carried out at numerous different points in the town, because there could be a variation of the weight, depending on the type of waste collected.

PROCEDURE

1. Select a container whose volume is known
2. Weigh the empty container (kg)
3. Fill up the container with waste.
4. Weigh the full container (kg)

COMPUTATION

Weight of the waste = Weight of the full container – Weight of the empty container

Waste density (kg/m^3) = Weight of the waste/Volume of the container

Box 2.1: Waste density

Exercise: Calculate the density of waste contained in a drum if the following data is given:

Weight of the full container (Wf) = 54 kg

Weight of the empty container (We) = 4 kg

Height of the container (H) = 1 m (the container is full!)

Diameter of the container (D)= 0.5 m

STEP 1: Calculation of the volume of the waste

STEP 2: Calculation of the weight of the waste

STEP 3: Calculation of the waste density

Solutions to waste density

STEP 1:

The volume of the container (V) can be calculated by using the following formula:

$$V = \frac{\pi \cdot D^2}{4} \cdot H = \frac{\pi \cdot 0.5^2}{4} \cdot 1 = 0.2\ m^3 = 200\ L$$

STEP 2: Calculation of the weight of the waste (W)

W = Wf – We = 54 – 4 = 50 kg

STEP 3: Calculation of the waste density (De)

2.8. How to evaluate the composition of the waste

Of which materials is the waste composed?

Material needed

- a plastic sheet to spread waste over for sorting
- gloves (for workers handling the waste)
- buckets whose weight is known
- weighing scale to weigh the waste with an accuracy of 100 grams

Procedure

1. Collect samples of waste of about 50 kg from households, offices and markets according to the different parts of the city. You can collect several plastic bags from all over the town in order to mix the waste and have a good sample.
2. When you get 50 kg of waste, go to the dumpsite.
3. Spread the sample over the plastic sheet.
4. Separate the waste on the plastic sheet into different types (e.g. vegetables/putrescible matter, paper, textiles, plastics, grass/leaves/wood, leather/rubber, metals, glass/ceramic, miscellaneous). Put then the separated waste into different buckets for weight measurement.
5. Measure the weight of each type of waste and record it in the data sheet.
6. Repeat steps 3. , 4. , 5. for each sample.

7. Dump all the waste properly and clean the equipment used.
8. Repeat steps 1. to 7. Every day for the duration of the study.

Type of waste	***Weight for each day (kg)***	***Total weight (kg)***	***Percentage (%)***
Vegetable/ putrescibile matter		(a)	(a)/(A) x 100
Paper		(b)	(b)/(A) x 100
Textiles		(c)	(c)/(A) x 100
Plastics		(d)	(d)/(A) x 100
Grass/leaves/wood		(e)	(e)/(A) x 100
Leather/rubber		(f)	(f)/(A) x 100
Metals		(g)	(g)/(A) x 100
Glass/ceramic		(h)	(h)/(A) x 100
Miscellaneous		(i)	(i)/(A) x 100
Total		**(A)**	**100**

The weights of waste in each category to put in the table are the samples of every day collection for a week at least (kg)

Total weight in each category, such as (a), (b), etc., is addition of all entries across the row.

Grand total weight = (a) + (b) + ... (i) = (A)

Box 2.2: Waste composition in Juba

Exercise: Calculate waste composition basing on the data reported in the following table.

Waste fraction	Production (kg/day)									
	M	T	W	T	F	Sa	Su	M	T	W
Vegetable/putrescible matter	3.0	2.0	2.0	2.0	4.0	3.0	3.0	2.0	4.0	4.0
Paper	4.0	1.0	2.0	2.0	3.0	3.0	2.0	3.0	1.0	2.0
Textiles	-	-	-	-	1.0	-	-	-	-	-
Plastics	0.5	3.0	1.0	1.0	-	5.0	3.0	2.0	2.0	1.0
Grass/leaves/wood	0.5	4.0	2.0	3.0	3.0	-	0.5	3.0	2.0	3.0
Leather/rubber	-	-	-	-	2.0	1.0	1.0	-	-	-
Metals	-	3.5	2.0	2.0	3.0	-	-	-	-	-
Glass/ceramic	1.0	3.5	1.0	1.0	-	2.0	0.5	3.0	2.0	3.0
Miscellaneous	2.0	3.0	1.0	2.0	3.0	2.0	4.0	3.0	1.0	3.0
TOTAL	11.0	20.0	11.0	13.0	19.0	16.0	14.0	16.0	12.0	16.0

STEP 1: Calculation of the total produced for each fraction

STEP 2: Calculation of the percentage of each fraction

Solutions to waste composition in Juba

STEP 1:

Waste fraction	Total production (kg/10 days)
Vegetable/putrescibile matter	3.0+2.0+2.0+2.0+4.0+3.0+3.0+2.0+4.0+4.0 = 29.0
Paper	4.0+1.0+2.0+2.0+3.0+3.0+2.0+3.0+1.0+2.0 = 23.0
Textiles	1.0
Plastics	0.5+3.0+1.+1.0+5.0+3.0+2.0+2.0+1.0 = 18.5
Grass/leaves/wood	0.5+4.0+2.0+3.0+3.0+0.5+3.0+2.0+3.0 = 21.0
Leather/rubber	2.0+1.0+1.0 = 4.0
Metals	3.5+2.0+2.0+3.0 = 10.5
Glass/ceramic	1.0+3.5+1.0+1.0+2.0+0.5+2.0+2.0+3.0 = 17.0
Miscellaneous	2.0+3.0+1.0+2.0+3.0+2.0+4.0+3.0+1.0+3.0 = 24.0
TOTAL	148.0

STEP 2:

Waste fraction	Percentage
Vegetable/putrescibile matter	29.0/148.0 * 100 = 19.6%
Paper	23.0/148.0 * 100 = 15.5%
Textiles	1.0/148.0 * 100 = 0.7%
Plastics	18.5/148.0 * 100 = 12.5%
Grass/leaves/wood	21.0/148.0 * 100 = 14.2%
Leather/rubber	4.0/148.0 * 100 = 2.7%
Metals	10.5/148.0 * 100 = 7.1%
Glass/ceramic	17.0/148.0 * 100 = 11.5%
Miscellaneous	24.0/148.0 * 100 = 16.2%
TOTAL	100.0%

3. Sizing different alternatives for solid waste collection

This chapter presents an exercise assessing four different alternatives for solid waste collection:

Alternative 1

Primary door-to-door collection is carried out by workers with wheelbarrows that carry the waste into skips. Then a truck with a crane collects the skips and carries them to the disposal site.

Alternative 2

Also in this case workers with wheelbarrows collect waste door–to-door but dispose it into fixed collection points. Then the waste is carried onto a tipper truck that transports it to the disposal site.

Alternative 3

The waste collection is carried out by a truck passing along the streets blowing its horn along its route to receive garbage from the households. When the trucks is full, it directly transports the waste to the disposal site

waste present in numerous street containers placed in the city and transports it to the landfill.

Alternative 4

A compactor truck collects the.

Equipment, personnel, capital and operation costs are defined for each collection alternative.

3.1. Alternative 1

The collection of waste in households is carried out by workers provided with wheelbarrows. The collected waste is then carried to skips placed inside the town. A truck with a crane passes and loads the skip full of garbage and transports it to the disposal site.

Attention: when the truck comes to carry the skip full of garbage, it should place an empty skip before carrying away the skip full of garbage.

A wheelbarrow

A truck carrying a skip

Figure 3.1 *Collection means for alternative 1*

The first step is to quantify how many skips one truck can transport to the landfill in one day.

This quantification needs some data:

- **Time to go from the town to the landfill and to come back**
- **Time to place an empty skip and to load the full skip on the truck**
- **Time to discharge the full skip in the landfill**

In this exercise, we suppose that:

- *Time to go to the landfill and to come back = 100 min*[1]
- *Time to place an empty skip and to load the full skip on the truck = 10 min*
- *Time to discharge the skip in the landfill = 10 min*

Then the time necessary for the truck to place an empty skip, to load one full skip, go to the landfill, discharge the skip and come back to the town is:

Time for one skip = 100 + 10 + 10 = 120 min = 2 hours

Another important datum is:

- **the work shift of the truck (i.e. how many hours does the truck work per day?)**

In this exercise we suppose that the work shift of the truck is equal to 12 hours per day.

[1] If this time is not known, you have to suppose:

1. the distance *d* between the city and the landfill
2. the velocity *v* of the truck

If we assume that the distance is 10 km and the velocity is 12 km/h, the time necessary to go to the landfill is:

$$T = \frac{d}{v} = \frac{10km}{12km/h} = 0.83h \text{ , that means: } T = 0.83h \times 60\,\mathrm{min}/h = 50\,\mathrm{min}$$

Since the truck has to go and to come back from the landfill, it needs 50 min x 2 times = 100 minutes

Moreover, we assume that two teams of employees work for the truck 6 hours a day. *Each team is composed of one driver plus two helpers.*

Now it is possible to quantify how many skips one truck can transport and discharge into the landfill in one day:

$$Number\_of\_skips = \frac{12\frac{h}{d}}{2\frac{h}{skip}} = 6\frac{skip}{d}$$

The truck goes to the landfill and comes back six times per day, then in one year it covers the following distance:

$$Distance = 20\frac{km}{trip} \times 6\frac{skips}{d} \times 365\frac{d}{y} = 43800\frac{km}{y}$$

Now we need another datum:

- **the volume of each skip**

We assume that the volume of one skip is 3 m^3

Consequently the volume of garbage that one truck can transport to the landfill is:

$$Volume_{day} = 6\frac{skip}{d} \times \frac{3m^3}{skip} = 18\frac{m^3}{d}$$

Now we have to define the number of inhabitants served by the truck. We need another datum:

- **the volume of waste produced by each inhabitant per day**

If this datum is not known, it can be calculated with other data:

- **the amount of waste produced by one inhabitant per day**
- **the density of waste**

We suppose:

- *waste production =* $0.4\frac{kg}{inh \times d}$
- *waste density =* $300\frac{kg}{m^3}$

Then the volume produced by one inhabitant in one day is:

$$V = \frac{0.4\frac{kg}{inh \times d}}{300\frac{kg}{m^3}} = 0.0013\frac{m^3}{inh \times d}$$

Consequently, the population served by one truck is:

$$P = \frac{18\frac{m^3}{d}}{0.0013\frac{m^3}{inh \times d}} = 13846 inh$$

Each truck serves 13846 inhabitants and discharge 6 skips a day in the landfill, so the number of inhabitants served by each skip is:

$$P_{skip} = \frac{13846 inh}{6 skip} = 2308\frac{inh}{skip}$$

Now we have to quantify the number of workers provided with wheelbarrows necessary to collect waste from households and discharge it in the skip.

We need another datum:

- **Number of inhabitants per hectare**

In this exercise *we suppose that this datum is 100 inh/ha*:

$$Area_{skip} = \frac{2308\frac{inh}{skip}}{100\frac{inh}{ha}} = 23.08\frac{ha}{skip}$$

This means that the area served is a square with sides of 480 meters.

Furthermore, we need to know:

- **Volume of waste carried in one wheelbarrow**
- **Number of inhabitants per household**

In this exercise *we assume that the volume of one wheelbarrow is 0.15 m^3 and one household is composed of 6 inhabitants*.

Consequently, one household produces:

$$V = 6\frac{inh}{hh} \times 0.0013\frac{m^3}{inh} = 0.0078\frac{m^3}{hh}$$

and one wheelbarrow can receive the waste produced by 19 household; in fact:

$$N_{hh} = \frac{0.15\frac{m^3}{wb}}{0.0078\frac{m^3}{hh}} = 19\frac{hh}{wb}$$

Now we have to quantify how many hours the workers need to collect the garbage and fill the wheelbarrow. We need another datum:

Number of households per km of street

We assume that the number of household per km is 30 (it means 180 inhabitants per km of street). The distance that the worker has to cover for 19 households is:

$$D = \frac{19\frac{hh}{wb}}{30\frac{hh}{km}} = 0.63\frac{km}{wb}$$

Furthermore *we assume that the velocity of the worker with wheelbarrow is 2 km/h and that it stops 3 minutes in each household*.

Consequently, the time the worker spends in the 19 households is equal to:

$$t = 3\frac{\min}{hh} \times 19\frac{hh}{wb} = 57\frac{\min}{wb}$$

and the time he needs to cover the street is:

$$t = \frac{0.63\frac{km}{wb}}{2\frac{km}{h}} = 0.315\frac{h}{wb} = 19\frac{\min}{wb}$$

It means that, as a whole, the worker needs 19 + 19 + 57 = 95 minutes = 1.58 hours to discharge one wheelbarrow in the skip.

Now we have to decide how long the **work shift for the worker with the wheelbarrow** is.

We assume that he works 8 hours per day. Consequently, in one day he can discharge 5 wheelbarrows into the skip (= 8 h / 1.58 h/load).

This means that the worker serves 95 households per day ($= 19\frac{hh}{wb} \times 5\frac{wb}{d}$), i.e. 570 inhabitants ($= 95\frac{hh}{d} \times 6\frac{inh}{hh}$).

Each skip serves 2308 inhabitants, then for each skip 4 workers are necessary to carry the waste from the households to the skip. In fact:

$$N_{workers} = \frac{2308\frac{inh}{skip}}{570\frac{inh}{worker}} = 4\frac{worker}{skip}$$

One truck serves six skips and each skip is served by four workers, then for one truck 24 workers with wheelbarrows are necessary.

Finally we can state that, in this case, the equipment and the workers necessary to serve a population of 13846 inhabitants are:

- **1 truck with a crane for the transport of skips working 12 h/d**
- **2 teams (one driver + 2 helpers) working 6 h/d**
- **7 skips (volume = 3 m^3)**
- **24 workers with wheelbarrow working 8 h/d**

In order to quantify the capital and management costs for the proposed alternative, we need some data:

- **cost of the truck with crane**
- **cost of skips (volume = 3 m3)**
- **cost of wheelbarrows**
- **annual wage of drivers**
- **annual wage of helpers for the drivers**
- **annual wage of the workers with wheelbarrows**
- **cost of fuel**
- **number of km covered by the truck with one liter of fuel**

In this exercise, we assume that:

- cost of the truck with crane = 8000 USD
- cost of skips (volume = 3 m^3) = 500 USD
- cost of wheelbarrows = 30 USD
- wheelbarrows lifetime = 1 year (therefore they are considered as operation costs)
- annual wage of drivers = 1200 USD/y
- annual wage of helpers (for the trucks) = 800 USD/y
- annual wage of the workers with wheelbarrows = 1000 USD/y
- cost of fuel = 1 USD/liter
- number of km covered by the truck with one liter of fuel = 4 km/liter

The cost per km covered by the truck is:

$$Cost_{km} = \frac{1\frac{USD}{L}}{4\frac{km}{L}} = 0.25\frac{USD}{km}$$

Now we can quantify the costs.

Capital costs:

Cost items	Unit	Cost per unit	Total
Truck	1	8000 USD	8000 USD
Skips	7	500 USD	3500 USD
Total			11500 USD

This means that the capital cost per each served inhabitant is:

Capital cost = 11500 USD/13846 inh = 0.83 USD/inh

Furthermore, the depreciation rate of the equipments has to be taken into consideration. It can be calculated by the following equation:

$$r = \frac{(i+1)^n \times i}{(i+1)^n - 1}$$

where:

r = depreciation rate

i = interest rate (assumed = 10%)

n = years of life of the equipment

The depreciation costs can be calculated as follows:

Cost items	Capital cost	n	i	r	Depreciation cost
Truck	8000 USD	5 y	0.1	0.26	2080 USD/y
Skips	3500 USD	3 y	0.1	0.40	1400 USD/y
Total					3480 USD/y

Operation costs:

Cost items	Unit	Cost per unit	Total
Equipment depreciation			3480 USD/y
Wheelbarrows	24	30 USD	720 USD
Drivers	2	1200 USD/y	2400 USD/y
Helpers	4	800 USD/y	3200 USD/y

Workers	24	1000 USD/y	24000 USD/y
Fuel	43800 km	0.25 USD/km	10905 USD/y
Subtotal			44705 USD/y
Maintenance + Administration + Accidents + Protective Clothes + etc.		20% of Subtotal	8941 USD/y
Total			53646 USD/y

This means that the operation cost per each served inhabitant is:

Operation cost = 53646 USD/13846inh = 3.87 USD/inh/y

Finally, it has to be considered that the above mentioned equipment is the minimum necessary equipment, but it would be better to have some extra capacity, that is:

- 1 extra truck for every 4 trucks in order to allow the programmed maintenance of each truck and avoid that the collection system collapses if a truck breaks down
- 1 extra skip for every 5 skips in order to have a bit more reserve volume for the collection of waste

For instance, a town of 50.000 inhabitants should need:

- 5 trucks: 4 trucks to serve the city and 1 more truck as a reserve
- 34 skips: 28 as the minimum number of skips to serve the city and 6 more skips

3.2. Alternative 2

The collection of waste in households is carried out by workers provided with wheelbarrows. The collected waste is then carried to transfer areas placed inside the town. A tipper truck passes and loads the garbage placed inside the transfer areas and transports it to the disposal site.

Attention: the pavements of the transfer areas have to be banked with respect to the level of the street in order to facilitate the transfer of waste into the truck.

	
A transfer area	A tipper truck

The first step is to fix the **volume of the tipper truck**.

In this exercise *we assume that volume is 10 m^3*.

Then we have to quantify how many loads the truck can carry to the landfill in one day.

This quantification needs some data:

- **Time to go from the town to the landfill and to come back**
- **Time to haul the solid waste from the transfer area into the truck**
- **Time to discharge the garbage in the landfill**

For this exercise, we assume that:

- *Time to go to the landfill and come back to the city = 100 min*
- *Time to haul the waste from the transfer area into the truck = 90 min*
- *Time to discharge the waste in the landfill = 10 min*

We have to quantify the number of workers necessary to carry the waste into the truck. Each worker is supposed to transfer 2 m^3 in 90 minutes[2]. Consequently 5 workers are necessary to load the garbage into the truck.

As a whole, the time necessary for the truck to be filled with garbage, go to the landfill, discharge the waste and come back to the town is:

Time for 1 load = 100 + 90 + 10 = 200 min = 3.33 h

We suppose that the truck works 10 h/d*, so it can transport 3 loads per day to the landfill, i.e. 30 m^3/d.*

The truck goes to the landfill and comes back three times per day, therefore in one year it covers the following distance:

[2] It means that the worker can transfer 400 kg/h. This leads to 600 kg in 1.5 h (= 90 min) and, assuming the density of waste equal to 300 kg/m^3, to 2 m^3 in 1.5 h.

$$Distance = 20\frac{km}{trip} \times 3\frac{skips}{d} \times 365\frac{d}{y} = 21900\frac{km}{y}$$

Now we have to define the number of inhabitants served by the truck. *Assuming the hypothesis of Alternative 1 (daily waste production per person = 0.0013 m³)*, the number of inhabitants served by one truck is:

$$P = \frac{30\frac{m^3}{d}}{0.0013\frac{m^3}{inh \times d}} = 23077inh$$

We posit placing transfer areas in the city whose volume is 6 m³. *One truck can consequently serve 5 transfer areas. In fact:*

$$N_{areas} = \frac{30\frac{m^3}{truck}}{6\frac{m^3}{area}} = 5\frac{areas}{truck}$$

The number of inhabitants served by each transfer area is:

$$P_{area} = \frac{23077\frac{inh}{truck}}{5\frac{area}{truck}} = 4615\frac{inh}{area}$$

Assuming the same hypotheses of the previous Alternative 1 (i.e. density of inhabitants = 100 inh/ha)*, the area served by one transfer area is:*

$$A_{area} = \frac{4615\frac{inh}{skip}}{100\frac{inh}{ha}} = 46.15\frac{ha}{skip}$$

This means that the area served is a square with sides of 679 meters.

The primary collection is done by workers with wheelbarrows. *Assuming the same hypotheses of Alternative 1, each worker can collect in one day the garbage produced by 570 inhabitants.*

Each transfer area serves 4615 inhabitants, then for each skip 8 workers are necessary to carry the waste from the households to the skip; in fact:

$$N_{workers} = \frac{4615 \dfrac{inh}{area}}{570 \dfrac{inh}{worker}} = 8 \frac{worker}{area}$$

One truck serves five transfer areas and each transfer area is served by 8 workers, then for one truck 40 workers with wheelbarrows are necessary.

Finally we can state that, in this case, the equipment and the workers necessary to serve a population of 23077 inhabitants are:

- **1 tipper truck whose volume is 10 m^3 working 10 h/d**
- **2 teams (one driver + 5 helpers) working 5 h/d**
- **5 transfer areas (volume = 6 m^3)**
- **40 workers with wheelbarrow working 8 h/d**

In order to quantify the capital and management costs for the proposed alternative, we need some data:

- **cost of the tipper truck (volume = 10 m3)**
- **cost of transfers areas (volume = 6 m3)**
- **cost of wheelbarrows**
- **annual wage of drivers (working 5 h/d)**
- **annual wage of helpers for the drivers (working 5 h/d)**
- **annual wage of the workers with wheelbarrows (working 8 h/d)**
- **cost of fuel**
- **number of km covered by the truck with one liter of fuel**

In this exercise, we assume that:

- cost of the tipper truck = 10000 USD
- cost of transfers areas = 1500 USD
- cost of wheelbarrows = 30 USD
- wheelbarrows lifetime = 1 year (therefore they are considered as operation costs)
- annual wage of drivers = 1000 USD/y
- annual wage of helpers (for the trucks) = 670 USD/y
- annual wage of the workers with wheelbarrows = 1000 USD/y
- cost of fuel = 1 USD/liter
- number of km covered by the truck with one liter of fuel = 4 km/liter

The cost per km covered by the truck is:

$$Cost_{km} = \frac{1 \dfrac{USD}{L}}{4 \dfrac{km}{L}} = 0.25 \frac{USD}{km}$$

Now we can quantify the costs.

Capital costs:

Cost items	Unit	Cost per unit	Total
Tipper truck	1	10000 USD	10000 USD
Transfer areas	5	1500 USD	7500 USD
Total			17500 USD

This means that the capital cost per each served inhabitant is:

Capital cost = 17500/23077 = 0.76 USD/inh

Furthermore, the depreciation rate of the equipment has to be taken into consideration. It can be calculated by the following equation:

$$r = \frac{(i+1)^n \times i}{(i+1)^n - 1}$$

where:
r = depreciation rate
i = interest rate (assumed = 10%)
n = years of life of the equipment

The depreciation costs can be calculated as follows:

Cost items	Capital cost	n	i	r	Depreciation cost
Tipper truck	10000 USD	5 y	0.1	0.26	2600 USD/y
Transfer areas	7500 USD	3 y	0.1	0.40	3000 USD/y
Total					5600 USD/y

Operation costs:

Cost items	Unit	Cost per unit	Total
Equipment depreciation			5600 USD/y
Wheelbarrows	40	30 USD	1200 USD
Drivers	2	1000 USD/y	2000 USD/y
Helpers for truck	10	670 USD/y	6700 USD/y
Workers with wheelbarrows	40	1000 USD/y	40000 USD/y
Fuel	21900 km	0.25 USD/km	5475 USD/y
Subtotal			60975 USD/y
Maintenance + Administration + Accidents + Protective Clothes + etc.		20% of Subtotal	12195 USD/y
Total			73170 USD/y

This means that the operation cost per each served inhabitant is:

Operation cost = 73170/ 23077 = 3.17 USD/inh/y

Finally, it has to be considered that the above mentioned equipment is the minimum necessary equipment, but it would be better to have greater capacity, that is:

- 1 extra truck for every 4 trucks in order to allow the programmed maintenance of each truck and avoid that the collection system collapses if a truck breaks down
- 1 extra transfer area for every 3 transfer areas in order to have a bit more reserve volume for the collection of waste

For instance, a town of 50.000 inhabitants should need:

- 3 trucks: 2 trucks to serve the city and 1 more truck as a reserve
- 15 transfer areas: 11 as the minimum number of areas to serve the city and 5 more transfer areas

3.3. ALTERNATIVE 3

In this case the waste collection is carried out by one truck that passes through the main routes around the city and stops every 100 meters. During its trip the truck blows its horn to get the attention of inhabitants to carry their own garbage to the truck.

In every stop, the truck can collect the waste from an area: 100m x 100m = 10000 m^2 = 1 ha

The number of inhabitants served in each stop can be quantified by knowing:

- **Number of inhabitants per hectare**

In this exercise *we assume that the number of inhabitants per hectare is 100 inh/ha.*

Moreover, *we assume that the time necessary for the truck to move between two collection points and to wait for the inhabitants coming with their own waste is 15 minutes*.

So, in one hour the truck stops 4 times and, consequently, serves 400 inhabitants.

Now we have to quantify the volume of the truck. We need some data:

- **Time to go from the town to the landfill and to come back**
- **Time to discharge the waste in the landfill**
- **Work shift of the truck**

We suppose that:

- *the round trip to the landfill is 100 minutes*
- *the time to discharge the waste in the landfill is 10 minutes*
- *the truck works 12 hours per day*

So time necessary for the truck to go to the landfill, discharge the waste and come back to the town is:

Time for one load = 100 min + 10 min = 110 min = 1.8 hours

The time remaining to collect waste is: 12 h – 1.8 h = 10.2 h

As stated before, the truck can serve 400 inh/h, so in 10.2 hours it can serve:

$$P = 400\frac{inh}{h} \times 10.2\frac{h}{d} = 4080\frac{inh}{d}$$

Assuming the hypothesis of Alternative 1 (daily waste production per person = 0.0013 m^3), the volume of waste collected by the truck is:

$$V_{waste} = 0.0013\frac{m^3}{inh} \times 4080\frac{inh}{d} = 5.3\frac{m^3}{d}$$

So we need a truck with a volume of at least 5.5 m^3 to collect the garbage of 4080 inhabitants for one day.

The truck works 12 hours per day, so it needs two teams (composed of one driver plus three helpers) working 6 hours per day each.

The truck goes to the landfill and comes back once per day (it means 20 km/d); moreover, the truck stops 41 times a day ($= 10.2\frac{h}{d} \times 4\frac{stops}{h} = 41\frac{stops}{d}$ ***). That means that it covers a distance equal to:***

$$d = 41\frac{stops}{d} \times 100\frac{m}{stop} = 4100m = 4.1km$$

So, in one day the truck cover 24.1 km (4.1 km for the waste collection + 20 km to go and come back from the landfill). Then in one year it covers the following distance:

$$Distance = 24.1\frac{km}{d} \times 365\frac{d}{y} = 8797\frac{km}{y}$$

Finally we can state that, in this case, the equipment and the workers necessary to serve a population of 4080 inhabitants are:

- **1 tipper truck with a volume of at least 5.5 m^3 working 12 h/d**
- **2 teams (one driver + 3 helpers) working 6 h/d**

In order to quantify the capital and operation costs for the proposed alternative, we need some data:

- **cost of the tipper truck (volume = 5.5 m3)**
- **annual wage of drivers (working 6 h/d)**
- **annual wage of helpers for the drivers (working 6 h/d)**
- **number of km covered by the truck with one litre of fuel**

In this exercise, we assume that:

- cost of the tipper truck = 8000 USD
- annual wage of drivers = 1200 USD/y
- annual wage of helpers (for the trucks) = 800 USD/y
- cost of fuel = 1 USD/litre
- number of km covered by the truck with one litre of fuel = 4 km/litre

The cost per km covered by the truck is:

$$Cost_{km} = \frac{1\frac{USD}{L}}{4\frac{km}{L}} = 0.25\frac{USD}{km}$$

Now we can quantify the costs.

Capital costs:

Cost items	Unit	Cost per unit	Total
Truck	1	8000 USD	8000 USD
Total			8000 USD

This means that the capital cost per each served inhabitant is:

Capital cost = 8000/4080= 1.96 USD/inh

Furthermore, the depreciation rate of the equipments has to be taken into consideration. It can be calculated by the following equation:

$$r = \frac{(i+1)^n \times i}{(i+1)^n - 1}$$

where:
r = depreciation rate
i = interest rate (assumed = 10%)
n = years of life of the equipment

The depreciation costs can be calculated as follows:

Cost items	Capital cost	n	i	r	Depreciation cost
Truck	8000 USD	5 y	0.1	0.26	2080 USD/y
Total					2080 USD/y

Operation costs:

Cost items	Unit	Cost per unit	Total
Equipment depreciation			2080 USD/y
Drivers	2	1200 USD/y	2400 USD/y
Helpers	6	800 USD/y	4800 USD/y
Fuel	8797 km	0.25 USD/km	2199 USD/y
Subtotal			11479 USD/y
Maintenance + Administration + Accidents + Protective Cloths + etc.		20% of Subtotal	2296 USD/y
Total			13775 USD/y

This means that the operation cost per each served inhabitant is:

Operation cost = 13775/4080= 3.38USD/inh/y

The above mentioned equipment is the minimum necessary equipment, but it would be better to have extra capacity, that is:

- 1 extra truck for every 5 trucks in order to allow the programmed maintenance of each truck and avoid that the collection system collapses if a truck breaks down

For instance, a town of 50.000 inhabitants should need:

- 14 trucks: 12 trucks to serve the city and 2 more trucks as a reserve

3.4. Alternative 4

In this case, we posit the use of a compactor truck with a capacity of 24 m^3 that collects the waste from street containers (volume = 1.1 m^3) placed all around the city.

A compactor truck

A street container (V = 1.1 m^3)

The compactor truck has a machine that cuts the waste charged into the truck in order to compact it. The waste density after the compaction is about 600 kg /m^3, so the waste that can be collected by the compactor truck per load is:

$$Weight\_of\_waste = 24\frac{m^3}{load} \times 600\frac{kg}{m^3} = 14400\frac{kg}{load}$$

We need a datum:

- **the daily waste production per person.**

Supposing, as in Alternative 1, that the daily waste production per person is 0.4 kg/inh/d, we can evaluate the number of inhabitants served by this type of truck per each load:

$$Pop = \frac{14400\frac{kg}{load}}{0.4\frac{kg}{inh}} = 36000\frac{inh}{load}$$

Now we have to quantify the number of street containers served by the truck. We need another datum:

- **the density of the waste in the street container**

In this exercise *we suppose that the density is 300 kg/m^3* (remember that the waste inside the street containers has not been compacted, yet).

The waste collected by the compactor truck is 14400 kg, so we can estimate the total volume of street containers that can be collect by the truck.

$$Volume\_Containers = \frac{14400kg}{300\frac{kg}{m^3}} = 48m^3$$

We know that the volume of each street container is equal to 1.1 m^3, so dividing the total volume into the volume of one street container, we can obtain the number of street containers that are necessary:

$$N°\_containers = \frac{48m^3}{1.1\frac{m^3}{container}} = 44containers$$

Now we have to calculate how many people are served by each container. It can be calculated as follows:

$$Inhab_{each\_container} = \frac{36000inh}{44container} = 818\frac{inh}{container}$$

Assuming, as in Alternative 1, that the population density is 100 inh/ha, we can determine the area served by each container as follows:

$$Area_{each\_container} = \frac{818\frac{inh}{stcont}}{100\frac{inh}{ha}} = 8.18ha$$

It means that the area served is a square with sides of 286 m.

In this alternative people have to carry their own garbage into the street containers, so these containers should not be too far from households. We assume that two containers are placed in 8.18 hectares (consequently, 88 containers are needed to serve 36000 inhabitants).

Now we have to quantify the time the truck needs to collect the waste, go to the landfill, discharge it and come back to the city.

This quantification needs some data:

- **Time to go from the town to the landfill and to come back**
- **Time to discharge the garbage in the landfill**
- **Velocity of the truck in the city**
- **Time to unload into the truck the garbage contained in one street container**

In this exercise, we assume that:

- Time to go to the landfill and come back to the city = 100 min
- Time to discharge the waste in the landfill = 10 min
- Velocity of the truck = 15 km/h
- Time to unload one street container = 3 min

The route that the truck has to cover to collect all the street containers can be calculated as follows:

$$Distance = 286 \frac{m}{containers} \times 44 \frac{containers}{load} = 12584 \frac{m}{load} = 12.6 \frac{km}{load}$$

and the time to cover this distance is:

$$Time = \frac{12.6 \frac{km}{load}}{15 \frac{km}{h}} = 0.84 \frac{h}{load} = 50 \frac{\min}{load}$$

The time necessary to unload all the 44 street containers into the truck is:

$$Time = 3 \frac{\min}{container} \times 44 \frac{containers}{load} = 132 \frac{\min ute}{load}$$

As a whole, the time the truck needs to load all the garbage, go to the landfill, unload the waste and come back is:

Time = 132 + 50 + 100 + 10 = 292 min ≈ 5 hours

If the truck works 10 hours per day, it can discharge 2 loads per day in the landfill, that means 88 containers and a population of 72000 inhabitants.

In terms of distance, it covers 20 + 12.6 = 32.6 km per load, that means 65.2 km per day and 23798 km per year.

Finally we can state that, in this case, the equipment and the workers necessary to serve a population of 72000 inhabitants are:

- **1 compactor truck with a volume of 24 m^3 working 12 h/d**
- **88 street containers (volume = 1.1 m^3)**
- **2 teams (one driver + 2 helpers) working 5 h/d**

In order to quantify the capital and operation costs for the proposed alternative, we need some data:

- **cost of the compactor truck**
- **cost of the street containers**
- **annual wage of drivers (working 5 h/d)**
- **annual wage of helpers for the drivers (working 5 h/d)**
- **number of km covered by the truck with one litre of fuel**

In this exercise, we assume that:

- cost of the compactor truck = 70,000 USD
- cost of the street containers = 350 USD
- annual wage of drivers = 1,100 USD/y
- annual wage of helpers = 600 USD/y
- cost of fuel = 1 USD/litre
- number of km covered by the truck with one litre of fuel = 4 km/litre

The cost per km covered by the truck is:

$$Cost_{km} = \frac{1\frac{USD}{L}}{4\frac{km}{L}} = 0.25\frac{USD}{km}$$

Now we can quantify the costs.

Capital costs:

Cost items	Unit	Cost per unit	Total
Compactor truck	1	70000 USD	70000 USD
Street containers	176	350 USD	61600 USD
Total			131600 USD

This means that the capital cost per each served inhabitant is:

Capital cost = 131,600/72,000 = 1.83 USD/inh

Furthermore, the depreciation rate of the equipment has to be taken into consideration. It can be calculated by the following equation:

$$r = \frac{(i+1)^n \times i}{(i+1)^n - 1}$$

where:
r = depreciation rate
i = interest rate (assumed = 10%)
n = years of life of the equipment

The depreciation costs can be calculated as follows:

Cost items	**Capital cost**	**n**	**i**	**r**	**Depreciation cost**
Compactor truck	70,000 USD	5 y	0.1	0.26	18,200 USD/y
Street containers	61,600 USD	2 y	0.1	0.58	35,728 USD/y
Total					53,928 USD/y

Operation costs:

Cost items	**Unit**	**Cost per unit**	**Total**
Equipment depreciation			53928 USD/y
Drivers	2	1000 USD/y	2,000 USD/y
Helpers for truck	4	670 USD/y	2,680 USD/y
Fuel	23798 km	0.25 USD/km	5,950 USD/y
Subtotal			64,558 USD/y
Maintenance + Administration + Accidents + Protective Clothes + etc.		20% of Subtotal	12,912 USD/y
Total			77,470 USD/y

This means that the costs per each served inhabitant are:

Operation cost = 77470/72000 = 1.08 USD/inh/y

The above mentioned equipment is the minimum necessary equipment, but it would be better to have some extra capacity, that is:

- 1 extra truck for every 3 trucks in order to allow the programmed maintenance of each truck and avoid that the collection system collapses if a truck breaks down
- 1 street container for every 2.5 hectares. In fact, in this case people have to carry their own wastes into the containers. For this reason these containers should not be too far from households.

For instance, a town of 200,000 inhabitants should need:

- 4 trucks: about 3 trucks to serve the city and 1 extra truck as a reserve
- 800 street containers (under the hypothesis that the population density is 100 inh/ha)

4. Homework activity

The trainer will divide the students in groups of 3-4 people. Each group will be provided with data and information concerning a specific context in a developing Country (see Annexes as an instance; alternative context descriptions may be prepared according to the trainer's experiences or according to specific requirements). Info and data should regard not only the technical aspects but also the socio-economic level of the population and some geographical or institutional constraints. According to the given data, each team group will design the waste collection system, giving a proper justification for the solutions proposed.

4.1. Evaluation criteria

Each group will have to produce the following deliverables:

- technical report of the collection system proposed with assumptions and calculation
- financial plan for the creation and management of the system (therefore including capital and operative costs)

The work done by each group has to be assessed according to the following criteria:

- completeness of materials to be delivered;
- justification of choices;
- correct calculation;
- concordance with constraints given;
- feasibility and soundness of the solution proposed;
- appropriateness of the solution proposed for the given context.

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FURTHER/SUGGESTED MATERIAL

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