# Decision Support Tool Process Module for Municipal Solid Waste Collection and Transportation for Developing Countries

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## INTRODUCTION

The pressing environmental and hygiene problems caused by solid wastes in developing countries can be significantly mitigated through the adoption of environmentally friendly technologies for waste treatment and disposal. Decision-support tools for selecting solid-waste management processes in developed countries exist already; however, developing country municipalities are facing problems with effective and efficient municipal solid waste management (SWM). Decision support tools for developed countries do not apply well directly to developing countries, due to differences in default values and assumptions like, type of equipment and waste, fraction of waste going to processing facilities, etc. Hence, there is an urgent need to develop decision support tools tailored for developing countries. These tools will be helpful to municipal officers, consultants, stakeholders, manufacturers, academicians, and others in making decisions.

A decision support tool's Collection & Transportation (C&T) process module was developed using a lifecycle approach to estimate the cost, diesel consumption, and greenhouse gas emissions (GHG) associated with municipal solid waste collection and transportation, which is the most fuel-intensive and often the highest budgetary item for municipalities for sustainable solid waste management. The module divides collection service areas into single-family residential, multi-family residential, and commercial sectors with sector-specific, user-defined characteristics, including population, waste generation rate, and waste composition. Waste is collected in various categories (e.g., residual waste, recyclables) with associated costs, energy use, and GHG emissions. The data for the process module were collected from the State of Gujarat in western India.

Two case studies of urban cities with populations of 300-400 thousand, Vapi Municipality (VM) and 5.5-6.5 Million, Ahmedabad Municipal Corporation (AMC)) were developed that represent the first applications of an assessment tool using life-cycle assessment for SWM.

The total capital cost for the C&T module for AMC was found to have a 9 % lower capital cost per ton as compared to VM, while total operating and maintenance costs were found to be 5% greater for the VM as compared to AMC. For AMC the O&M cost was found to be 7.5 times the capital cost, while for VM it was found to be 6.28 times. The C&T in AMC consumes 80 % of the total diesel used for overall solid waste management and 35 % in VM.

The optimization results indicated that diverting waste from open dumping to a regional landfill reduced GHG emissions (by 51% for AMC, in conjunction with diversion to vermi-composting, and 44% for VM); diverting waste from vermi-compost facilities to open dumps reduced costs (by 29% for AMC, and 18% for VM), and diverting waste from the regional landfill (for AMC) or open dumps (for VM) to vermi-compost facilities reduced diesel consumption (by 4% for AMC and 10% for VM), when compared with the current scenario, based on primary data collected from municipalities. Sensitivity analysis illustrated the relative impact of changing individual parameters (waste tonnage, % diversion to different facilitates; vermicomposting, regional landfill, etc.) on the cost, diesel consumption, and GHG emissions.

## DISCUSSION OF METHODS

Most developing countries do not have existing infrastructure for collection of municipal solid waste. This means that a low percentage of waste is typically collected. Table 2.8 provides an overview of the percent of waste collected in developing countries. It is critical that the collection module to be developed allow users to input a percent of waste collected that is lower than 100%.

**Table 1 Collection rates in developing countries/cities**

| Country/Locality | Collection rate (%) | References |
|---|---|---|
| South Africa – general | 50 | DEAT (2007) |
| urban kerbside | 80 | Karani and Jewasikiewitz (2007) |
| Abidjan (Côte d'Ivoire) | 30–40 | Parrot et al. (2009) |
| Dakar (Senegal) | 30–40 | Parrot et al. (2009) |
| Dar es Salaam (Tanzania) | 48 | Parrot et al. (2009) |
| Lomé (Togo) | 42.1 | Parrot et al. (2009) |
| Ndjamena (Chad) | 15–20 | Parrot et al. (2009) |
| Nairobi (Kenya) | 30–45 | Parrot et al. (2009) |
| Nouakchott (Mauritania) | 20–30 | Parrot et al. (2009) |
| Yaoundé (Cameroon) | 43 | Parrot et al. (2009) |
| China – general | 79 | Suocheng et al. (2001) |
| Indian cities | About 70 | Sharholy et al. (2008) and Pattanaik and Reddy (2010) |
| Lahore (Pakistan) | 60 | Batool and Ch (2009) |

Source: (Friedrich et al., 2011)

The type and size of vehicles used plays a vital role in the emissions from collection and transportation of waste. The waste is transported via primary transportation from door-to-door of individual households to the transfer station or directly to the treatment facility in small counties and municipalities. Primary transportation of waste involves door-to-door collection of waste from individual households (single family and multifamily) and commercial establishments. Secondary transportation involves collection of waste from transfer stations to processing facilities and from processing facilities to the disposal site. Secondary transportation is as important as primary transportation as it reduces the machinery, time, effort, personnel and above all it alleviates and rationalizes the work. Parameters affecting primary and secondary transportation and collection are number of trips, hours spent by the driver, time taken by the vehicle, fuel consumption, etc., which are necessary for calculation of emissions from the equipment and vehicles used for waste transportation. Primary and Secondary transportation are majorly carried out using trucks and compactors in developed countries, while different types of vehicles/machinery are used in the developing countries (vehicles of small size capacity, e.g. skid steer machine, front end loader with backhoe 35 HP).

Optimized selection of specific type of vehicles/ machinery for primary and secondary transportation at the processing site and dumping/ sanitary landfill site is much needed, as it affects the numbers of vehicles to be used and hours of operation of vehicles. The kind of vehicles used in developed and developing countries differ; hence, vehicles need to be added for developing countries' scenario. The waste gathered at the transfer station is transferred after partial segregation to the treatment facilities though secondary transportation. The amount of waste collected and transported is proportional to the amount of waste received at the processing facilities. Vehicles are also used at the treatment plants and disposal sites to dispose of the residual from the treatment plants. Usually in developing countries the residual from the treatment plant is around 20-30% of the input waste.

Vehicles should be selected, based on the type of waste and waste density,. A typical compacting vehicle used for waste transportation increases the density of material, while the volume is decreased, as shown in Figure 1, below. The reduction in volume depends on both the type of waste and the design of the compaction mechanism.

Vehicles used for compaction, however, differ in developing countries from those in developed countries. In developing countries, many small and advanced level trucks and skid steer type vehicles are because vehicle movement is restricted in many areas, and there is not enough space to route big compactors. Mobility and 360-degree rotational movement of small vehicles plays an important role in the collection and transportation of waste in developing countries. The collection and transportation module will need to be modified to include these smaller compaction vehicles.

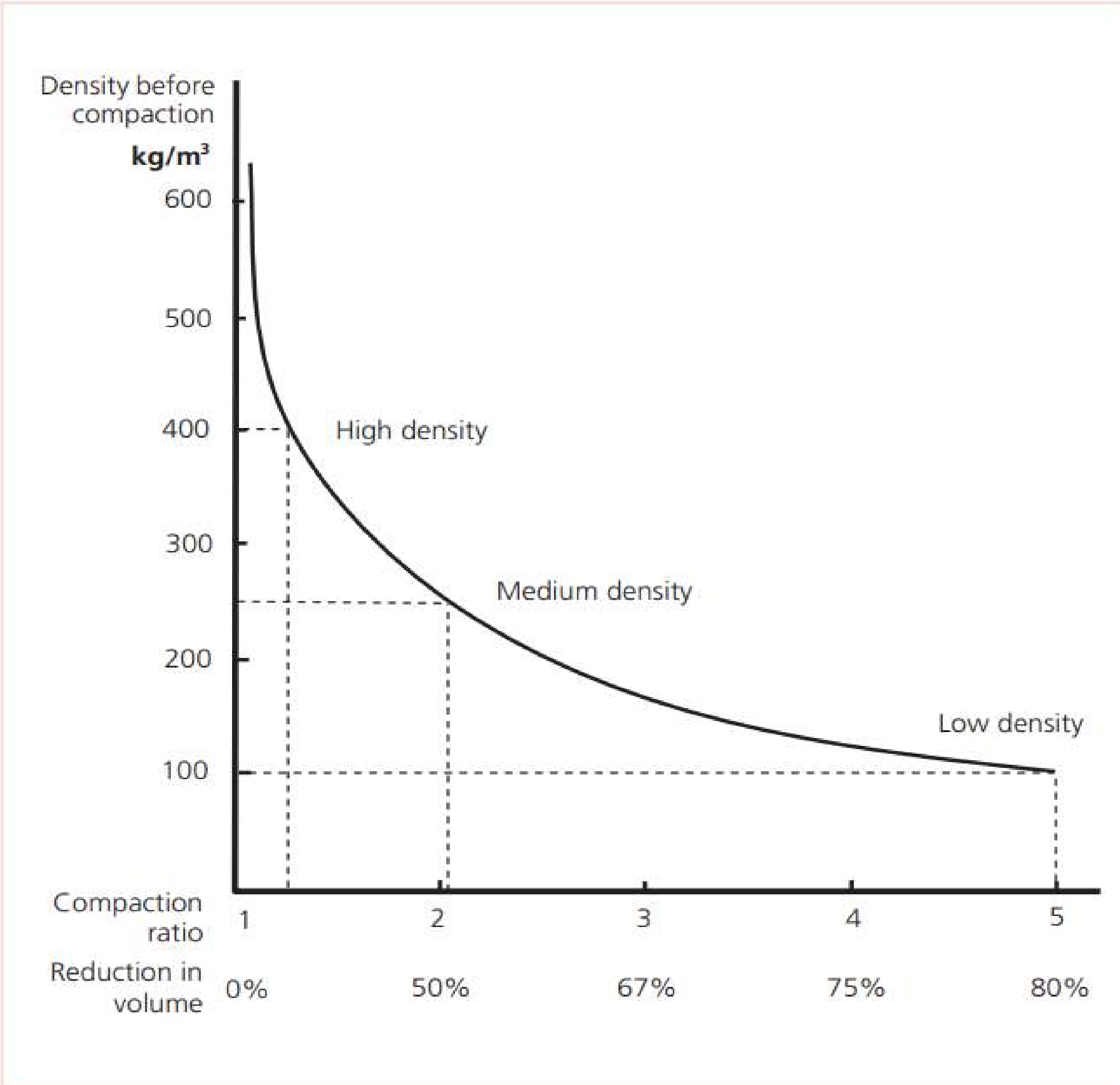
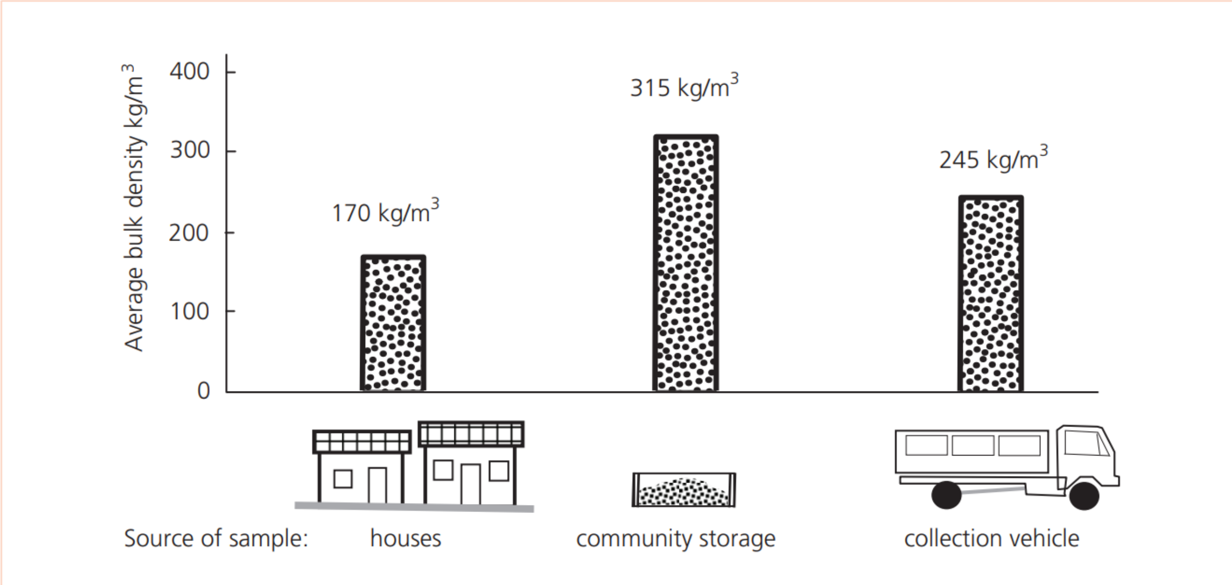



**Fig. 1. Compacting vehicle used for waste transportation and its effect on waste density.**
Source: UN-HABITAT, Collection of MSW report, 2018.

Waste densities in developing countries are higher than waste densities in developed countries because in developing countries, there is higher amount of organic waste fraction which has higher density compared to dry recyclables and, therefore, fewer compactor trucks for collection and transport are used (Barton et al., 2008 and Imam et al., 2008), resulting in lower emissions. The transportation module will need to be modified to reflect these differences. Average bulk densities of waste to processing or disposal facilities in developing countries are shown in Figure 2 below.




Source: UNHSP-UN-HABITAT, 2010; Collection transportation of municipal solid waste to processing or disposal facilties in developing countries.

**Fig. 2 Average bulk densities with different sources of waste**

**Collection and Transportation Process module input methodology:** An option is provided for the user to input the percent of waste collected, since it is often substantially less than 100% for developing countries. Waste generated, collected, and transferred is estimated for single family (SF), multifamily (MF) and commercial (COM)'s sectors. The type of equipment/vehicle used for waste collection and transportation affects air pollutants emitted based on the engine, fuel used and the way it is driven. The types of equipment added to the SWAT Collection/Transportation Module were chosen based on usage, availability in the market, and developing country costs (capital and operating). Most municipalities do not have budget to buy large amounts of equipment; they rent the equipment from other municipalities or prioritize equipment selection for waste transportation based on necessity and budget.

**Emission factors calculations:** Emission factors are typically expressed as pollutant weight divided by a unit weight, volume, distance, or duration of the pollutant-emitting activity (e.g., kilograms of particulate matter emitted per megagram). Total emissions of traditional air pollutants or greenhouse gases from combustion of any kind of fossil fuel consumption during waste transportation will be calculated. Emission factors for various types of equipment, with units of g/mile will be used. Argonne National Lab's GREET model was used for equipment for which the same manufacturer and model are used in developing countries as for the US. Emission factors obtained from Ramachandra et al. (2016) are measured values for vehicles specific to Indian conditions. They are also used by other Asian countries; they use the same models of equipment. The activity in terms of miles traveled by each equipment for transporting the total waste tonnage is user input to the process module.

**Capital and operating costs methodology:** The total cost for collection and transportation is the sum of the capital cost plus the operating cost. Present worth can be converted to annual value using engineering economy factors. Similarly, future cash inflow from salvage values will be converted from future to annual using engineering economy annual-given-future factors. Capital costs include the cost of equipment, , tire costs and life expectancy for the 13 types of equipment while Operating costs can be calculated as Equation 1, below;

***Op<sub></sub>***

$$Op_{Cost} = \text{Personnel (Laborers/helpers, Operators/drivers, manager/engineer/ administrative staff) cost} + \text{Fuel cost} + \text{Tire cost} + \text{Repair cost} + \text{RTS operating cost} + \text{(Insurance, license, and tax cost)} + \text{Contingency cost} + \text{Miscellaneous cost} \quad \textbf{Eq. 1}$$

Personnel cost includes workers that drive the trucks and other vehicles to collect the waste, as well as personnel that operate the transfer station. The tool divides personnel costs into three categories: 1) Laborer/helper and 2) Operator/driver, and 3) Manager/engineer and administrative staff.

**Diesel fuel consumption equation**: Diesel fuel consumption can be calculated according to equation 2, below

$$Diesel\ consumption\ per\ ton\ of\ waste = \frac{Diesel\ consumption\ per\ vehicle\ per\ day}{Waste\ collected\ per\ vehicle\ per\ day} \quad \textbf{Eq. 2}$$

Where:

Diesel consumption per ton of waste: Gallons/Ton or Liter/Ton
Diesel consumption per vehicle per day: Gallons/day-vehicle
Waste collected per vehicle per day: Ton/day-vehicle

## RESULTS AND DISCUSSION FOR BASELINE/CURRENT WASTE MANAGEMENT SYSTEMS IN AMC AND VM

For AMC and VM, the Chhota Hathi (container mounted on 4-wheel minitruck") has the highest emissions for all pollutants. The number of pieces of equipment for C & T of waste for VM was less compared to AMC; thus, AMC produced greater emissions. Large emissions from Chhota Hathi (4-wheel mini truck container mounted) were expected, as this equipment are frequently used in developing countries to commute between narrow streets and transport waste to the primary processing facility or refuse transfer station.

It was noted that for VM, the open body truck has the highest costs ($ 542,857), whereas for AMC refuse compactor truck has the highest costs ($ 9,350,000). Refuse compactor trucks are not very useful in VM as it is a small municipality with less waste as compared to AMC. Based on the number of vehicles required, the total cost for equipment varies significantly. In both cases, tire costs for the Chhota Hathi (4-wheel Mini Truck) were highest. The number of pieces of equipment for C & T of waste for VM was less compared to AMC, which was the reason behind

AMC having total costs as 10 times more than VM. The cost variation was as expected: large cities (5-6.5 M) have greater refuse compactor truck usage, and 4-wheel Mini Trucks are used more in small cities (300-430,000).

Total equipment capital and operating costs for VM were obtained as $17.89 ($/Ton), while for AMC they were $15.76 ($/Ton), which is in range with the literature values of $ 9-24 ($/Ton) (World Bank, 2012). AMC, having higher population, achieves economies of scale, which is the reason for its ($/Ton) value being lower than VM. Operation and maintenance constitute around 90% of the total costs (Equipment capex and opex cost, $/Ton) for both cases. Lifetime of 7 years was assumed for equipment; capital costs and salvage values were converted to annual values based on engineering economy factors.

Different types of equipment like 3-wheeler auto, Tractor mounted Galvanized Container, Refuse Compactors, Front End Loader 50-76 HP, Skid Steer Machine, Tractor Mounted Road Sweeper Vacuum Machine, etc. were used in AMC and VM for collecting and transporting waste to transfer station where it is aggregated and then hauled ot the landfill. The highest amount of diesel was consumed by the Tractor Mounted Road Sweeper Vacuum Machine for both the cases. Average diesel consumption for VM lies between 0.14-0.73 Gallons/Ton, while for AMC diesel consumption range was obtained as 0.17- 2.19 Gallons/Ton, which is expected because of the higher number of pieces of equipment being used by AMC compared to VM.

## SUMMARY OF RESULTS:

It was noted that emissions were higher for AMC as compared to VM, while emissions are site-specific and dependent on the type of vehicle selection and usage. The refuse transfer operating costs were 2.5 times greater than the capital cost ($/Ton) and higher than the AMC and VM operating costs. Diesel consumption for AMC was 2 times compared to VM.

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