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Optimum municipal solid waste collection using geographical information system (GIS) and vehicle tracking for Pallavapuram municipality

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Abstract

Waste collection and transportation is the contact point between waste generators and waste management systems. A proposal for an innovative model for the collection and transportation of municipal solid waste (MSW) which is a part of a solid waste management system using a spatial geo database, integrated in a geographical information system (GIS) environment is presented. Pallavapuram is a fast-developing municipality of Chennai city in the southern suburbs about 20 km from Chennai, the state capital of Tamil Nadu in India. The disposal of MSW was previously occurring in an indiscriminate and irrational manner in the municipality. Hence in the present study an attempt was made to develop an engineered design of solid waste collection using GIS with a vehicle tracking system and final disposal by composting with investment costs. The GIS was used to analyse existing maps and data, to digitize the existing ward boundaries and to enter data about the wards and disposal sites. The proposed GIS model for solid waste disposal would give information on the planning of bins, vehicles and the optimal route. In the case of disposal, composting would be a successful strategy to accelerate the decomposition and stabilization of the biodegradable components of waste in MSW.

Keywords

Pallavapuram, municipal solid waste (MSW), waste collection, geographical information system (GIS), vehicle tracking system (VTS)

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Introduction

Urbanization is one of the most evident global changes worldwide. The rapid growth in urban populations leads to a dramatic increase in solid waste generation, with a severe socio-economic and environmental impact (Karadimas and Loumos 2008). Many cities in developing Asian countries face serious problems in managing their solid waste. According to Idris et al. (2004), the annual waste generation increases in proportion to the rise in population in these countries and issues related to disposal have become challenging as more land is needed for the ultimate disposal of waste. In the case of some Indian cities, the collection, transportation and disposal of municipal solid waste (MSW) are done in an unscientific manner. Uncontrolled dumping of waste on the outskirts of towns and cities has created overflowing landfills, which are impossible to reclaim due to the haphazard manner of dumping. They also cause serious environmental implications in terms of groundwater pollution and global warming (Gupta et al., 1998). The rapid growth rates combined with their huge population base has left many Indian cities deficient in infrastructure services such as water supply, sewage and solid waste management (Ghose and Dikshit 2006). Thus waste management is a major problem for municipal corporations as it involves a huge expenditure and receives scant attention.

An examination of the related literature reveals that the most advanced methodology used to automate the process

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of waste planning and management is the design and construction of integrated systems using GIS environments (Karadimas and Loumos 2008). In this context, several systems have been implemented to serve various purposes, such as the location of recycling drop-off stations (Chang and Wei 2000), the precise estimation of solid waste generation using the local population density and income group distribution (Vijay et al., 2005), as well as municipal waste generation forecasting (Katsamaki et al., 1998; Dyson and Chang 2005). Ahluwalia et al. (2006) aimed to address the issues involved in the planning and design of a computer waste management system in an integrated manner. Klang et al. (2006) investigated how system analyses have been carried out in a Swedish county and was perceived by local municipal officers to support the decision-making process. Moreover, Higgs (2006) presented participative approaches that use information technology (IT)-based methods, utilizing combined GIS and multi-criteria evaluation techniques that could involve the public in the decision-making process at different stages of the waste facility management process. Furthermore, in this context hauled container systems (HCS) are preferred over stationary container systems (SCS) as HCS provide greater flexibility in container location planning, discourage scavenging by animals and keep the surrounding environment clean (Naresh Kumar and Sudha Goel 2009).

Optimization of the routing system for collection and transport of solid waste is an important component of an effective solid waste management system. Developing an optimal routing scheme for waste disposal involves the determination of a number of selection criteria, which is a tedious job for a planner to do manually. Hence, in the present study an attempt was made to propose an efficient management system for MSW taking into consideration the defects in the existing management of waste.

Existing MSW management in Pallavapuram, Municipality

Pallavapuram is a suburban town within the city of Chennai and also a municipality in Kancheepuram district in the Indian state of Tamil Nadu. It is a nearby hub for suburban trains as well as trains bound to the south. Its surrounding areas include Pammal, Anakaputhur, Pozhichalur, Nagalkeni, etc. The municipality is located on highway NH-45 and all the buses have to pass through this site. The regional settings of the Pallavapuram municipality are presented in Table 1. The municipality generates solid waste at an average rate of 86 Mtonnes every day. The garbage is collected from about 179 km of roads, streets and by-lanes by sweepers with collection vehicles in 42 wards. Currently, waste is dumped at several open grounds. Segregation and storage of waste at source are generally absent resulting in a disorganized primary collection system. Even reusable materials get soiled and their quality deteriorates. Piles of waste are left to spread litter along the roadsides and open spaces producing strong offensive odours and leachate. The municipality has already prepared drawings of each and every major and minor street for all the divisions but the work schedule and allotment of collection routes is done purely on an ad hoc basis. Many streets and by-lanes are not swept regularly and furthermore, there is hardly any co-ordination between sweepers and collection vehicles. The road sweepers are not provided with modern tools and scant attention is paid to the health and safety aspects of the road sweepers' activities.

Table 1. Regional setting of Pallavapuram municipality*

Sl. no.	Details	Description
1	Latitude (N)	12° 58′ 06″
2	Longitude (E)	80° 09′ 10″
3	Area extent (km^2)	18
4	Number of wards	42
5	Number of streets	1249
6	Length of highways (km)	13
7	Number of slums	19
8	Population	166 917 (2001)
9	Length of municipal roads (km)	179.52
10	Bus stands	2
11	Railway stations	2
12	Markets	2
13	Water bodies	11
14	Parks	11
15	Hospitals	21
16	Marriage halls	30

*Source: Pallavapauram Municipality (PMC 2008).

Primary collection of waste and methods of storage

In 2001 there were about 26 765 households in Pallavapuram, together with a large number of commercial and industrial establishments and institutional buildings. Primary collection of waste from the doorstep has been introduced in 43.96% households and establishments. The waste is collected from door-to-door using bullock carts or handcarts. In the absence of the facility of doorstep collection in the entire city, 56.04% people continue to throw their waste onto the streets, open spaces, drains, etc. (PMC 2008).

Dustbins (steel, dumper, concrete and masonry bins) have been provided at selected locations within each ward. The municipality has also provided bins in selected collection points built of brickwork and scattered through the area for temporary storage. These bin stores are an open space enclosed on three sides with masonry walls about 1.25 m high, with capacities ranging from 15 to 40 m^3 and located in the congested areas containing narrow winding streets. Most of the bins are not in good condition and the rest

Table 2. Existing primary collection vehicles*

Sl. no	Description of vehicle	Quantity
1	Sweepers staff strength	280
2	Tricycle	38
3	Concrete bins	650
4	Tricycle containers	10
5	Population (2001)	166 917
6	No. of households	26 765

*Source: Pallavapauram Municipality (PMC 2008).

Table 3. Existing secondary collection vehicles*

Sl. no	Description of vehicle	Quantity
1	TATA 407	1
2	Swaraj Mazda	2
3	Eicher lorry	3
4	Dumper placer	1
5	Compactor	–

*Source Pallavapauram Municipality (PMC 2008).

have been damaged during loading by the vehicles. Most of the bins overflow and some locations lack bins leading to waste scattering. Table 2 gives the details of the existing primary collection vehicles.

Uncollected waste often ends up in drains, causing blockages, which result in flooding and unsanitary conditions. Flies and mosquitoes also breed in blocked drains and in rainwater in some constituents of solid waste. Flies are very effective vectors that spread disease including malaria, dengue and chic kun gunia. The open burning of waste also causes air pollution which includes dioxins that are particularly hazardous. Aerosols with dust can spread fungi and pathogens from the decomposed waste. Fires that occur in disposal sites also cause illness and reduce visibility. They also make disposal sites dangerously unstable and cause explosions.

Secondary collection of waste

The collected garbage is then transported to an existing dumping site near a lake. For this activity, agro trucks, cargo vehicles and swaraj mazda are used. Table 3 gives the details of existing secondary collection vehicles. At present there is no transfer station in the municipality and the disposal sites are located near water bodies causing water pollution. Uncovered transportation of waste during primary and secondary collection has also resulted in littering en route to the disposal site. Further, it adds to the poor visual impacts due to wind-blown plastic and lighter debris.

Bearing in mind the shortcomings as discussed, in the present study a conceptual model of the waste management practices to be followed in this municipality has been developed to define the methodology for an engineered collection of waste collection, transportation and disposal.

Methodology

The framework of the proposed waste management plan was mainly based on the following considerations.

- Evaluation of appropriate method for on-site storage.
- Evaluation of appropriate method of bulk storage of waste.
- Design of primary and secondary collection of waste.
- Incorporation of geographical information system (GIS) for primary and secondary collection.
- Design of in-vessel composting system for biodegradable waste.
- Financial expenditure on whole solid waste management plan.

Evaluation of appropriate method for on-site storage

Source segregation was first suggested involving the provision of a two-bin system (Green for Bio degradable waste and Red for Non Bio degradable waste) for every household.

Evaluation of appropriate method of bulk storage of waste

For the purpose of computation of number of bins for on-site storage, the population for the study period (2007) was estimated from population data of census year 2001 obtained from the municipality office. To forecast the population of individual municipalities and other local bodies within the municipalities, the exponential curve method was found to be suitable (when considering also the trends in growth over the past decades). The exponential curve method uses the formula given in Equation (1) as in the Second Draft Master Plan – IIa (CMDA 2006a)

$$P_{t+n} = P_t * e^{rt} \tag{1}$$

where P_t is the population at time t; P_{t+n} is population at time $t+n$; n is the number of time periods; and r is the average percentage of change in population over the past time period.

Per capita disposal rates were estimated for low, medium and high income groups. Waste samples were collected directly from these generators for 15 days at the disposal site and weighed. This allowed for more detailed analysis of these waste streams and the per capita generation was computed based on Equation (2). The average waste generation rate was taken as 0.5 kg capita $^{-1}$ day^{-1} using

$$\text{Generation rate (kg capita}^{-1}\text{ day}^{-1}) = \text{Quantity of solid waste (kg day}^{-1})/\text{population} \tag{2}$$

Design of primary and secondary collection

Based on the population density, width of roads and availability of space a primary collection system of waste was proposed for the municipality. Some extra capacity was provided for unforeseen factors such as slippage, overflow, etc. and the container utilization factor was assumed to be 150% (Ghose and Dikshit 2006). After studying the existing solid waste management in Pallavapuram, it was decided to recommend hauled container systems.

Hauled container systems (HCS) are usually used where large quantities of waste are generated and large size containers are used. These systems are operated such that each container is picked up at its location at the source and transported to the treatment facility, disposal site or transfer station where it is emptied. The empty container is then returned to its original location. Alternatively it is deposited at the next pick-up location on the route in exchange for a full container (Peavy et al., 1985).

Using this approach in the recommended system, tricycles, dumper placers and compactors were to be used for primary collection. Auto rickshaws were avoided, as they pollute the ambient air and involve high operation and maintenance costs. The MSW were to be transported from the collection points directly to the present dumping site at Ganapathipuram. Then bulk refuse carriers would be used to transport waste to the compost yard at Vengatamangalam about 25 km from this location.

Incorporation of GIS for primary and secondary collection

The proposed GIS model for solid waste disposal required the planning of bin locations, vehicles and optimal routing. The base year 2007 was selected and all the project components were designed taking into consideration the defects in the existing system as discussed above. Global positioning system (GPS)–GIS integrated systems have some important applications in the field of solid waste management systems. These applications include vehicle tracking systems (VTS) for fleet management and vehicle navigation systems. There follow some details of the prior use of these applications and in particular the application of GPS-GIS integrated systems for network travel time studies, which are useful for locating the movement of vehicles.

GIS had already been used to digitize the existing sanitary ward boundaries, roads, water bodies and to create attribute data about the wards and disposal sites based on maps and data and the GPS – Magellan Explorer 2000 series model had been used to locate the dumper placer bins. The municipal authorities, together with the study team, identified the location of dumper placer bins in each ward. The scanned municipality base map was digitized in Map Info Professional, version 8 using points, lines and polygon tools as shown in Figure 1.

The base map was registered with known ground coordinates (latitude and longitude of known reference

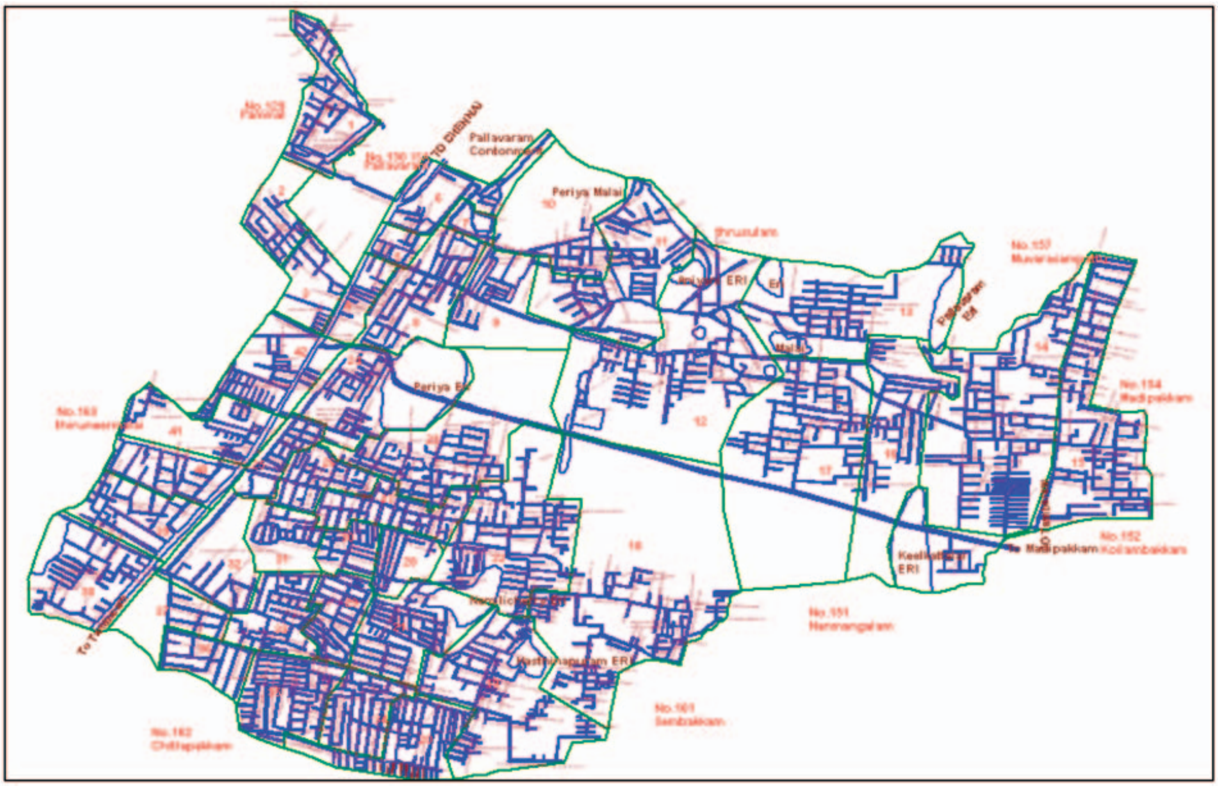

Figure 1. Digitized map of the municipality.

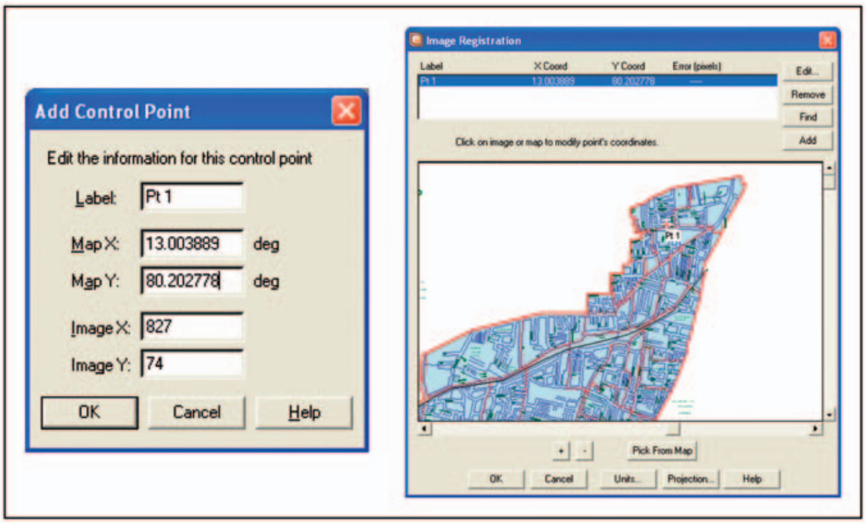

Figure 2. Image registration for the digitized map of the municipality.

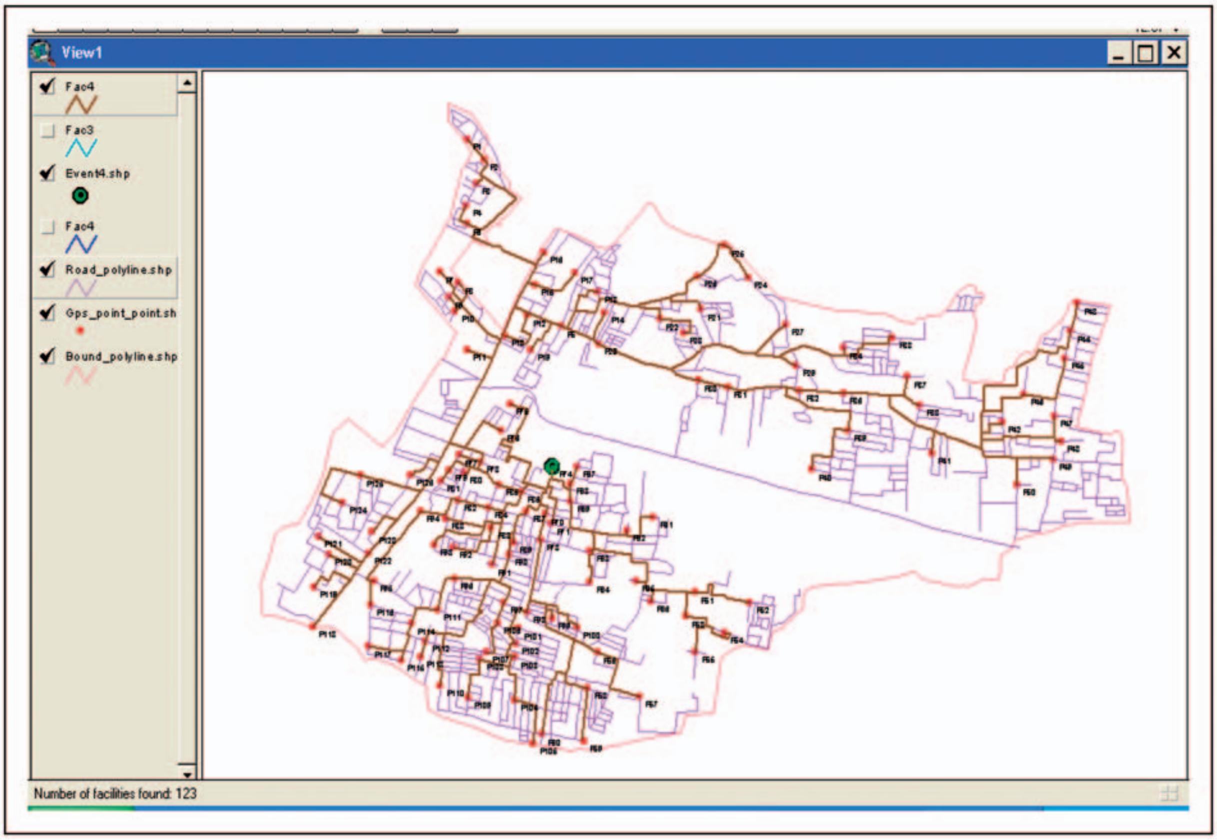

Figure 3. Map showing road network connecting bins and transfer station.

landmarks) as shown in Figure 2. The themes such as road network, boundary, wards, dumper placer collection points (Easy GPS), transfer points and annotations were created followed by transfer into Arcview GIS 3 as in Figure 3. The generated GIS maps provide efficient information such as collection point locations, MSW transport means and their routes, and the number of disposal sites and their attributes.

Finally, the VTS provided end-to-end solutions for online vehicle tracking that made it possible to track vehicles anywhere, anytime and from any place. Transport Management Solutions (TMS 360–360 degree) software provided tools for dumper placer vehicle tracking which include networking and the installation of the systems and creation of the monitoring centre for GIS, management of information system (MIS) and GPS, located in the municipal offices.

Disposal of waste

An in-vessel composting facility had been designed in a modular format consisting of 60 modules, each with capacity to process 250 Mtonnes of organic material per day.

Results and discussion

Based on the use of Equation (1) and population data of 2001 from the municipality, the forecast population for the study period (2007) was calculated in the following manner.

Annual growth rate, –1.5 (CMDA 2006b)

Time $t = 6$ years

$$\text{Population in 2007} = \text{population in 2001 } (166\,917) * e^{(1.5*6)} = 177\,070 \quad (3)$$

Further from the per capita generation rate, 0.50 kg evaluated from the survey work carried out previously, the quantity of MSW to be generated was evaluated:

$$\text{Waste generation (Mtonnes)} = 177\,070 * 0.50/1000 = 88.53 \text{ Mtonnes} \quad (4)$$

Design of bulk storage, primary collection system

Collection of solid waste was to be carried out by using suitable vehicles. The type of vehicle to be used depends on the type of collection bin and width of road (Ghose and Dikshit 2006). Tricycles had to be used for door-to-door collection in each street. The collected waste from the tricycles was then to be conveyed to the dumper bins placed at suitable locations using GPS. Pallavapuram municipality was divided into 42 wards in which 110 dumper placers, as per the calculations shown in Table 4, needed to be placed at different locations in the city along its major roads. The dumper placer bins would be loaded by hook-loaded vehicles using an HCS system.

The tricycles would consist of one crew member who would be fully responsible for the collection and disposal of the waste from each house. The crew would collect the waste from each house in the morning from 0700 h until evening in all the wards. Each crew would collect the waste from each house and dump it into the tricycle.

Analysis of HCS (primary collection)

The time required per trip is equal to the pick-up time per trip, at site and haul times given by Equation (5) and listed in Table 5

$$T_{HCS} = P_{HCS} + s + a + bx \quad (5)$$

Table 4. Design of primary collection bins

Quantity of waste that will be collected from Pallavapuram municipality	88.53 Mtonnes
Adding 150% overflow (Ghose and Dikshit 2006)	139.55 Mtonnes
Density of waste	0.50 tonne m^{-3}
Volume of waste (m^3)	$139.55/0.50 = 265.6\ m^3$
No of bins	
Dumper placer bins (capacity of each dumper placer bins = 2.5 m^3)	$265.6/2.5\ m^3 = 110$ bins

where P_{HCS} is the pick-up time per trip in minutes; s is the time spent at the disposal site = 0.127 h trip^{-1} (Peavy et al., 1985); a is the empirical haul constant (h trip^{-1}) = 0.05 h trip^{-1} (Peavy et al., 1985); b is the empirical haul constant (h km^{-1}) = 0.01 h km^{-1} (Peavy et al., 1985); x is the round trip haul distance (km trip^{-1}) = 2.80 (Table 5)

$$P_{HCS} = (pc + uc + dbc) = 0.4019 \text{ km trip}^{-1} \text{ as in Table 5}$$

where pc is the time to pick-up a container in h trip^{-1}; uc is the time to unload the container in h trip^{-1}; dbc is the time to drive between containers in h trip^{-1}

$$T_{HCS} = 0.4019 + 0.127 + 0.05 + 0.01 * 2.80 = 0.675 \text{ h trip}^{-1}$$

The number of trips that can be made per vehicle per day with an HCS was determined from Equation (6)

$$N_d = [H(1 - w) - (t_1 + t_2)]/T_{HCS} \quad (6)$$

where N_d is the number of trips made per day; H is the length of the working day (11 h); t_1 is the time spent driving from the dispatch site at the beginning of day (0.16 h) (Peavy et al., 1985); t_2 is the time spent driving to the dispatch site at the end of the day (0.10 h) (Peavy et al., 1985); w is the off-route factor (0.15) (Peavy et al., 1985)

$$N_d = [11(1 - 0.15) - (0.16 + 0.10)]/0.675 = 14 \text{ trips day}^{-1}.$$

If a vehicle carries two bins, then 28 bins would be cleared per day by a vehicle.

$$\text{Length of work day, } H = [N_d * T_{HCS} + (t_1 + t_2)]/(1 - w) \quad (7)$$

$$H = [14 * 0.7981 + (0.16 + 0.10)]/(1 - 0.15) = 7 \text{ h}.$$

It was found that the working time of 7 h derived from Equation (7) had to be followed for collecting the waste from the bins, excluding the time of lunch. The collected garbage in 2.5 m^3 bins was to be transported by dumper bin vehicles to the proposed transfer station at Ganapathipuram,

Table 5. Analysis of HCS system and route distance (primary collection)

Sl. no	Start point	Ward	End point	Route*	Distance x (km)*	Average	Speed (km h^{-1})	Time (min)	$pc+uc$ (h trip^{-1})	dbc (h trip^{-1})	P_{HCS} (h trip^{-1})	Average P_{HCS} (h trip^{-1})	Vehicle
1	P69	23	Dumpsite	R69	0.37	0.37	25	0.0148	0.4	0.0002	0.4002	0.4002	A1
2	P67	23	Dumpsite	R67	0.45		25	0.018	0.4	0.0003	0.4003		A2
3	P68	23	Dumpsite	R68	0.32	0.385	25	0.0128	0.4	0.0002	0.4002	0.40025	A2
4	P70	27	Dumpsite	R70	0.46		25	0.0184	0.4	0.0003	0.4003		A3
5	P71	27	Dumpsite	R71	0.52	0.49	25	0.0208	0.4	0.0003	0.4003	0.4003	A3
6	P87	27	Dumpsite	R87	0.42		25	0.0168	0.4	0.0003	0.4003		A4
7	P89	30	Dumpsite	R89	0.87	0.645	25	0.0348	0.4	0.0006	0.4006	0.40045	A4
8	P88	27	Dumpsite	R88	0.5		25	0.02	0.4	0.0003	0.4003		A5
9	P91	30	Dumpsite	R91	1.08	0.79	25	0.0432	0.4	0.0007	0.4007	0.4007	A5
10	P80	25	Dumpsite	R80	0.96	0.96	25	0.0384	0.4	0.0006	0.4006	0.4006	A6
11	P84	27	Dumpsite	R84	0.79	1.015	25	0.0316	0.4	0.0005	0.4005	0.4005	A6
12	P63	22	Dumpsite	R63	0.91		25	0.0364	0.4	0.0006	0.4006		A7
13	P64	22	Dumpsite	R64	1.17	1.04	25	0.0468	0.4	0.0008	0.4008	0.4007	A7
14	P90	30	Dumpsite	R90	0.79		25	0.0316	0.4	0.0005	0.4005		A8
15	P97	29	Dumpsite	R97	1.35	1.07	25	0.054	0.4	0.0009	0.4009	0.4007	A8
16	P79	25	Dumpsite	R79	1.09	1.09	25	0.0436	0.4	0.0007	0.4007	0.4007	A1
17	P82	27	Dumpsite	R82	1.03		25	0.0412	0.4	0.0007	0.4007		A9
18	P83	27	Dumpsite	R83	1.24	1.135	25	0.0496	0.4	0.0008	0.4008	0.40075	A9
19	P81	25	Dumpsite	R81	1.19	1.14	25	0.0476	0.4	0.0008	0.4008	0.4008	A10
20	P61	22	Dumpsite	R61	1.36		25	0.0544	0.4	0.0009	0.4009		A11
21	P62	22	Dumpsite	R62	1.06	1.21	25	0.0424	0.4	0.0007	0.4007	0.4008	A11
22	P76	24	Dumpsite	R76	1.48		25	0.0592	0.4	0.001	0.4010		A12
23	P77	25	Dumpsite	R77	1.04	1.26	25	0.0416	0.4	0.0007	0.4007	0.40085	A12
24	P92	31	Dumpsite	R92	1.3	1.3	25	0.052	0.4	0.0009	0.4009	0.4009	A10
25	P98	21	Dumpsite	R98	1.23		25	0.0492	0.4	0.0008	0.4008		A13
26	P101	21.3	Dumpsite	R101	1.5	1.365	25	0.06	0.4	0.001	0.4010	0.4009	A13
27	P99	21	Dumpsite	R99	1.4	1.4	25	0.056	0.4	0.0009	0.4009	0.4009	A14
28	P93	31	Dumpsite	R93	1.43	1.43	25	0.0572	0.4	0.001	0.401	0.401	A14
29	P96	37	Dumpsite	R96	1.49	1.49	25	0.0596	0.4	0.001	0.401	0.401	A15
30	P75	24	Dumpsite	R75	1.52	1.52	25	0.0608	0.4	0.001	0.401	0.401	A15
31	P60	20	Dumpsite	R60	2.52		25	0.1008	0.4	0.0017	0.4017		A16
32	P73	27,28	Dumpsite	R73	0.67	1.595	25	0.0268	0.4	0.0004	0.4004	0.4009	A16
33	P65	22	Dumpsite	R65	1.58		25	0.0632	0.4	0.0011	0.4011		A17
34	P66	22,19	Dumpsite	R66	1.68	1.63	25	0.0672	0.4	0.0011	0.4011	0.4011	A17
35	P126	41	Dumpsite	R126	1.68	1.68	25	0.0672	0.4	0.0011	0.4011	0.4011	A18
36	P106	29	Dumpsite	R106	1.52		25	0.0608	0.4	0.001	0.401		A19
37	P107	33,35	Dumpsite	R107	1.86	1.69	25	0.0744	0.4	0.0012	0.4012	0.4011	A19
38	P102	21,29	Dumpsite	R102	1.6		25	0.064	0.4	0.0011	0.4011		A20
39	P100	21	Dumpsite	R100	1.62	1.62	25	0.0648	0.4	0.0011	0.4011	0.4011	A20
40	P103	21,34	Dumpsite	R103	1.84	1.72	25	0.0736	0.4	0.0012	0.4012	0.4012	A18
41	P11	3	Dumpsite	R11	2.12		25	0.0848	0.4	0.0014	0.4014		A21
42	P85	23,27	Dumpsite	R85	1.42	1.77	25	0.0568	0.4	0.0009	0.4009	0.40115	A21
43	P114	33,37	Dumpsite	R114	2.09		25	0.0836	0.4	0.0014	0.4014		A22
44	P111	33	Dumpsite	R111	1.8	1.945	25	0.072	0.4	0.0012	0.4012	0.4013	A22
45	P78	25	Dumpsite	R78	0.87		25	0.0348	0.4	0.0006	0.4006		A23
46	P20	9	Dumpsite	R20	3.05	1.96	25	0.122	0.4	0.002	0.4020	0.4013	A23
47	P112	33,	Dumpsite	R112	2.1		25	0.084	0.4	0.0014	0.4014		A24
48	P113	36	Dumpsite	R113	2.23	2.165	25	0.0892	0.4	0.0015	0.4015	0.4013	A24
						37.79							24

(continued)

Table 5. Continued

Sl. no	Start point	Ward	End point	Route*	Distance x (km)*	Average	Speed (km h^{-1})	Time (min)	$pc+uc$ (h $trip^{-1}$)	dbc (h $trip^{-1}$)	P_{HCS} (h $trip^{-1}$)	Average P_{HCS} (h $trip^{-1}$)	Vehicle
49	P123	39	Dumpsite	R123	2.17	2.17	25	0.0868	0.4	0.0014	0.4014	0.4014	B1
50	P56	19	Dumpsite	R56	1.87		25	0.0748	0.4	0.0012	0.4012		B2
51	P57	19	Dumpsite	R57	2.5	2.185	25	0.1	0.4	0.0017	0.4017	0.40145	B2
52	P52	18	Dumpsite	R52	2.5	2.215	25	0.1	0.4	0.0017	0.4017	0.4017	B3
53	P95	32	Dumpsite	R95	2.14		25	0.0856	0.4	0.0014	0.4014		B4
54	P116	37	Dumpsite	R116	2.3	2.22	25	0.092	0.4	0.0015	0.4015	0.4013	B4
55	P53	18	Dumpsite	R53	2.04	2.04	25	0.0816	0.4	0.0014	0.4014	0.4014	B5
56	P108	35	Dumpsite	R108	2.07		25	0.0828	0.4	0.0014	0.4014		B6
57	P109	35	Dumpsite	R109	2.44	2.255	25	0.0976	0.4	0.0016	0.4016	0.4015	B6
58	P54	18	Dumpsite	R54	2.55	2.295	25	0.102	0.4	0.0017	0.4017	0.4017	B7
59	P110	35	Dumpsite	R110	2.32	2.32	25	0.0928	0.4	0.0015	0.4015	0.4015	B7
60	P104	34	Dumpsite	R104	2.13		25	0.0852	0.4	0.0014	0.4014		B8
61	P105	20	Dumpsite	R105	2.58	2.355	25	0.1032	0.4	0.0017	0.4017	0.40155	B8
62	P59	20	Dumpsite	R59	2.55	2.355	25	0.102	0.4	0.0017	0.4017	0.4017	B9
63	P86	23,27	Dumpsite	R86	0.6	2.335	25	0.024	0.4	0.0004	0.4004	0.4004	B9
64	P124	39,41	Dumpsite	R124	2.74		25	0.1096	0.4	0.0018	0.4018		B10
65	P125	41	Dumpsite	R125	2.11	2.425	25	0.0844	0.4	0.0014	0.4014	0.4016	B10
66	P121	39	Dumpsite	R121	2.72		25	0.1088	0.4	0.0018	0.4018		B11
67	P122	39	Dumpsite	R122	2.25	2.485	25	0.09	0.4	0.0015	0.4015	0.40165	B11
68	P115	36	Dumpsite	R115	2.39		25	0.0956	0.4	0.0016	0.4016		B12
69	P117	36	Dumpsite	R117	2.59	2.49	25	0.1036	0.4	0.0017	0.4017	0.40165	B12
70	P55	18	Dumpsite	R55	2.51	2.51	25	0.1004	0.4	0.0017	0.4017	0.4017	B13
71	P8	2	Dumpsite	R8	2.68		25	0.1072	0.4	0.0018	0.4018		B14
72	P10	2	Dumpsite	R10	2.56	2.62	25	0.1024	0.4	0.0017	0.4017	0.40175	B14
73	P120	38	Dumpsite	R120	2.64	2.64	25	0.1056	0.4	0.0018	0.4018	0.4018	B13
						39.92							14
74	P12	4,5	Dumpsite	R12	2.48		25	0.0992	0.4	0.0017	0.4017		C1
75	P19	8	Dumpsite	R19	2.94	2.71	25	0.1176	0.4	0.002	0.402	0.40185	C1
76	P7	2	Dumpsite	R7	2.8		25	0.112	0.4	0.0019	0.4019		C2
77	P9	2	Dumpsite	R9	2.63	2.715	25	0.1052	0.4	0.0018	0.4018	0.40185	C2
78	P15	5,6	Dumpsite	R15	2.6		25	0.104	0.4	0.0017	0.4017		C3
79	P17	6,7	Dumpsite	R17	2.99	2.795	25	0.1196	0.4	0.002	0.402	0.40185	C3
80	P13	4	Dumpsite	R13	2.93		25	0.1172	0.4	0.002	0.402		C4
81	P16	6	Dumpsite	R16	2.81	2.87	25	0.1124	0.4	0.0019	0.4019	0.40195	C4
82	P119	38	Dumpsite	R119	2.88	2.88	25	0.1152	0.4	0.0019	0.4019	0.4019	C5
83	P118	38	Dumpsite	R118	2.95	2.95	25	0.118	0.4	0.002	0.4020	0.4020	C5
84	P5	8	Dumpsite	R5	2.73		25	0.1092	0.4	0.0018	0.4018		C6
85	P18	7	Dumpsite	R18	3.23	2.98	25	0.1292	0.4	0.0022	0.4022	0.4020	C6
86	P14	9	Dumpsite	R14	3.21	3.21	25	0.1284	0.4	0.0021	0.4021	0.4021	C7
87	P4	1	Dumpsite	R4	3.64		25	0.1456	0.4	0.0024	0.4024		C8
88	P6	1	Dumpsite	R6	3.44	3.54	25	0.1376	0.4	0.0023	0.4023	0.40235	C8
89	P22	10	Dumpsite	R22	3.74		25	0.1496	0.4	0.0025	0.4025		C9
90	P23	11	Dumpsite	R23	4.13	3.935	25	0.1652	0.4	0.0028	0.4028	0.40265	C9
91	P26	11	Dumpsite	R26	4.06	4.06	25	0.1624	0.4	0.0027	0.4027	0.4027	C7
92	P21	10	Dumpsite	R21	4.07	4.07	25	0.1628	0.4	0.0027	0.4027	0.4027	C10
						38.72							10
93	P1	1	Dumpsite	R1	4.38		25	0.1752	0.4	0.0029	0.4029		D1
94	P2	1	Dumpsite	R2	4.18	4.28	25	0.1672	0.4	0.0028	0.4028	0.40285	D1

(continued)

Table 5. Continued

Sl. no	Start point	Ward	End point	Route*	Distance *x* (km)*	Average	Speed (km h^{-1})	Time (min)	*pc* + *uc* (h $trip^{-1}$)	*dbc* (h $trip^{-1}$)	P_{HCS} (h $trip^{-1}$)	Average P_{HCS} (h $trip^{-1}$)	Vehicle
95	P24	11	Dumpsite	R24	4.73		25	0.1892	0.4	0.0032	0.4032		D2
96	P25	11	Dumpsite	R25	4.41	4.57	25	0.1764	0.4	0.0029	0.4029	0.40305	D2
97	P31	12	Dumpsite	R31	4.11		25	0.1644	0.4	0.0027	0.4027		D3
98	P39	17	Dumpsite	R39	5.28	4.695	25	0.2112	0.4	0.0035	0.4035	0.4031	D3
99	P30	12	Dumpsite	R30	3.87	3.87	25	0.1548	0.4	0.0026	0.4026	0.4026	D4
100	P28	11,12	Dumpsite	R28	4.7		25	0.188	0.4	0.0031	0.4031		D5
101	P29	12	Dumpsite	R29	4.7	4.7	25	0.188	0.4	0.0031	0.4031	0.4031	D5
102	P40	17	Dumpsite	R40	5.86	4.865	25	0.2344	0.4	0.0039	0.4039	0.4039	D4
103	P32	12	Dumpsite	R32	4.67		25	0.1868	0.4	0.0031	0.4031		D6
104	P37	16	Dumpsite	R37	5.62	5.145	25	0.2248	0.4	0.0037	0.4037	0.4034	D6
105	P36	13,17	Dumpsite	R36	5.01		25	0.2004	0.4	0.0033	0.4033		D7
106	P38	16	Dumpsite	R38	5.62	5.315	25	0.2248	0.4	0.0037	0.4037	0.4035	D7
107	P33	13	Dumpsite	R33	5.6		25	0.224	0.4	0.0037	0.4037		D8
108	P34	13	Dumpsite	R34	5.15	5.375	25	0.206	0.4	0.0034	0.4034	0.40355	D8
109	P41	16	Dumpsite	R41	6.01		25	0.2404	0.4	0.004	0.404	0.404	D9
						42.82							9
110	P42	14	Dumpsite	R42	6.6	6.6	25	0.264	0.4	0.0044	0.4044	0.4044	E1
111	P50	14	Dumpsite	R50	6.75	6.75	25	0.27	0.4	0.0045	0.4045	0.4045	E1
112	P49	14,15	Dumpsite	R49	6.84	6.84	25	0.2736	0.4	0.0046	0.4046	0.4046	E2
113	P47	14,15	Dumpsite	R47	7.1		25	0.284	0.4	0.0047	0.4047		E3
114	P48	15	Dumpsite	R48	7	7.05	25	0.28	0.4	0.0047	0.4047	0.4047	E3
115	P45	14,15	Dumpsite	R45	7.52		25	0.3008	0.4	0.005	0.4050		E4
116	P46	14	Dumpsite	R46	6.96	7.24	25	0.2784	0.4	0.0046	0.4046	0.4048	E4
117	P43	14,15	Dumpsite	R43	7.92		25	0.3168	0.4	0.0053	0.4053		E5
118	P44	14,15	Dumpsite	R44	7.71	7.815	25	0.3084	0.4	0.0051	0.4051	0.4052	E5
						42.3							5
					2.80							0.4019	

a location in the south of GST road in Pallavapuram, which had been selected as the transfer station. Table 6 presents the design of primary collection vehicles requirements and shows that five dumper placer vehicles would be required to collect the waste from 110 bins. However, a dumper vehicle would carry two bins in a trip, with the number of trips based on the distance that had been calculated and all the trips were scheduled in such a way that each vehicle designated in Table 7 would cover a distance of approximately 34 km day^{-1}. Each vehicle designated as A, B, C, D and E with one driver and two collection labourers would take 7 h to cover loading/unloading the waste and transporting the waste to the transfer station. The number of trips reduced as the distance from the dumper bin to the transfer station increased as in Table 5. All the bins would be cleared in such a way that two bins carried by a vehicle would lie on the same route to the transfer station so that when a vehicle cleared the first bin from the start point, it would go to the second bin and then proceed to the transfer station.

The proposed tricycle cart would have six to eight bins each of 25 L capacity (separate bins for biodegradable waste as well as inert and non-biodegradable waste) and carry up to 200 kg of waste. Each collection labourer would make five trips per day and so the total number of tricycles required is 140 as in Table 6. The speed and delay for the peak and off peak periods was required for travel corridors and on sections of road network in the municipalities to validate the transport model and help to develop the speed–flow relationship for the dumper placer bin vehicles. The floating car technique was utilized to obtain data wherein the driver was instructed to follow the designated route course, while maintaining the average speed of other traffic and accompanied by trained members of the team who recorded the cumulative time at specified timing points to obtain the average link time of the road network It was found that on average 25 km h^{-1} was the optimum speed selected for the dumper vehicle.

Design of secondary collection system

In the Pallavapuram municipality the existing dumping site is located at Peria Eri. It was recommended that the dumping site should be cleared and all the waste safely segregated at

Table 6. Design of primary collection vehicles

Dumper placer bins		Tricycles	
Total required as in Table 3	118	Number of trips by a tricycle	5
Number of trips by a vehicle	28	Quantity of waste collected by a tricycle	0.2 Mtonnes
Number of vehicles required	118/28 – 4	Total quantity of waste collected	139.55 Mtonnes
Providing 25% allowance	5	Number of tricycles required	139.55/(5 * 0.2) = 140

Table 7. Details of distance per trip of primary collection vehicles

Sl. no	Vehicle	Distance (km)	Number of trips allotted
1	A	31.62	25
2	B	34.04	14
3	C	34.52	10
4	D	35	7
5	E	35	5
		Total	61

the proposed transfer station in Ganapathipuram and disposed of in the treatment facility at the final disposal site at Venkatamangalam.

Analysis of HCS (secondary collection)

The time required per trip is equal to the pick-up time per trip, at site and haul times given by Equation (8). In this analysis of HCS secondary collection, the speed and time taken to drive between containers was taken as 40 km h^{-1} and 0.4 h trip^{-1}, respectively.

$$P_{\mathrm{HCS}} = (pc + uc + dbc) = 0.90\,\text{km trip}^{-1} \text{ (from Table 8)}$$

$$T_{\mathrm{HCS}} = P_{\mathrm{HCS}} + s + a + bx \tag{8}$$

$T_{\mathrm{HCS}} = 0.90 + 0.127 + 0.05 + 0.01 \;*\; 20.08 = 1.28$ h trip^{-1} (Peavy et al., 1985)

The number of trips that could be made per vehicle per day with a HCS was determined in the following manner:

$$N_{\mathrm{d}} = [H(1 - w) - (t_1 + t_2)]/T_{\mathrm{HCS}} \tag{9}$$

$N_{\mathrm{d}} = [8(1-0.15)-(0.16 + 0.10)]/1.28 = 5$ trips day^{-1} (Peavy et al., 1985)

The working hours for secondary collection was computed and given below:

$$H = [N_{\mathrm{d}} * T_{\mathrm{HCS}} + (t_1 + t_2)]/(1 - w) \tag{10}$$

H = [5 * 1.40 + (0.16 + 0.10)]/(1 – 0.15) = 8 h (Peavy et al., 1985).

It was found that a working time of 8 h had to be followed for collecting the waste from the transfer station apart from the normal daily working hours of 11 h, including time for lunch. The collected garbage had to be transported to the proposed final disposal site by tipper lorries and bulk refuse carrier. Table 9 represents the number of tipper lorries and bulk refuse carrier required for the secondary collection. The tipper and bulk refuse carriers were assumed to carry a payload of 10 Mtonnes and, based on the number of trips (assumption) and collectable quantity, the number of vehicles was calculated.

Optimal GIS routing model for collection and disposal of solid waste

The proposed GIS model for solid waste disposal involved the planning of bins, vehicles and optimal routing. ARC-VIEW GIS is a complete and integrated system for the creation, management, integration, and analysis of geographic data. It consists of a geo-referenced spatial database, which includes all required parameters for waste management. In the present application these parameters involved the sanitary wards, collection points, transportation road network, as well as the location and capacity of disposal sites and its road connections with the different wards. Then the closest facility and the best route were determined at the same time using the Network Analyst. The numbers of locations and facilities are specified in Figure 4. The shortest route map with location details is presented in Figure 5 for primary collection and Figure 6 for secondary collection.

Pallavapuram municipality is divided into 42 wards in which 118 collection points were identified around the municipality instead of 110 bins, as designed, due to the locations of some bins being affected by practical constraints. Ganapathipuram is specified as the transfer station for collection points.

Vehicle tracking systems

Vehicle tracking systems are to be used for guiding vehicles to their destination. These systems usually use GPS or inertial navigation systems or a combination of both for positioning the vehicle. The VTS uses a computer, which determines the position of a vehicle, plans the route and gives the directions to the driver. The driver gives the location of his/her

Table 8. HCS system for secondary collection

Start point	End point	Distance (x) (km)	Speed (km h^{-1})	Time (min)	$pc+uc$ (h $trip^{-1}$)	dbc (h $trip^{-1}$)	P_{HCS} (h $trip^{-1}$)
Ganapathipuram	Venkatamangalam	20.08	40	30.12	0.50	0.4	0.90

Table 9. Design of secondary collection

		Secondary collection	
Sl. no.	Equipment	Tipper lorry	Bulk refuse carrier
1	Area coverage	40% of waste from transfer station to dumping yard	60% of waste from transfer station to dumping yard
2	Pay load or waste per trip (Mtonnes) (assumed)	10	10
3	Collectable quantity (Mtonnes) (assumed)	35.412 (0.4 * 88.53)	53.12 (0.6 * 88.53)
4	No of trips per vehicle	5	5
5	No of vehicles required	35.412/(10 * 5) = 1	53.12/(10 * 5) = 2

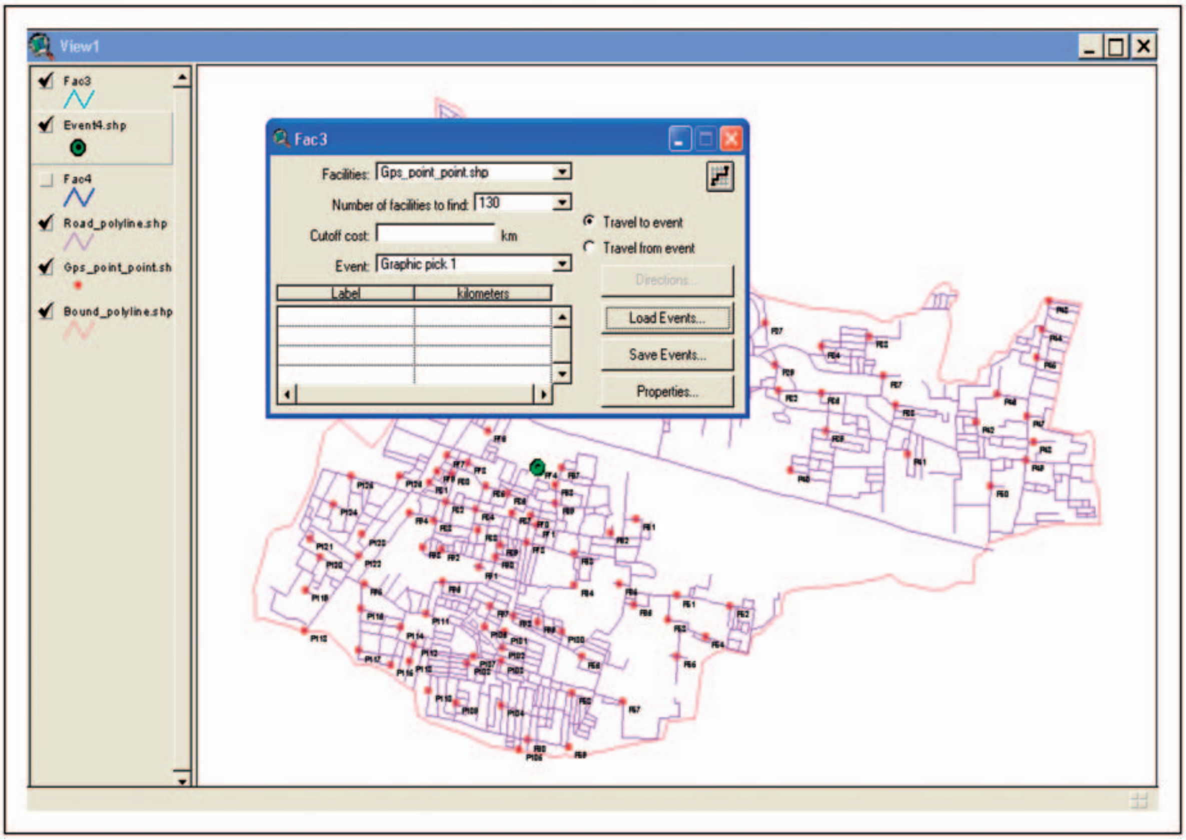

Figure 4. Map showing ARC GIS using network analyst.

destination when starting his journey and the computer guides the driver by giving either audio and/or visual instructions. The route the computer plans is usually the optimized route, which is either the route optimized for distance or the route can be the most or the least used route (Jurgen, 1998). The VTU unit in Pallavapuram municipality consists of GPS and GPRS modules and proprietary embedded hardware and software integrated with the ARCGIS-generated map. The GPS unit is most regularly fitted under the dashboard or in the bumper of the vehicle. The control station software receives the information through short message service (SMS) from the vehicle unit, once it reaches the location of

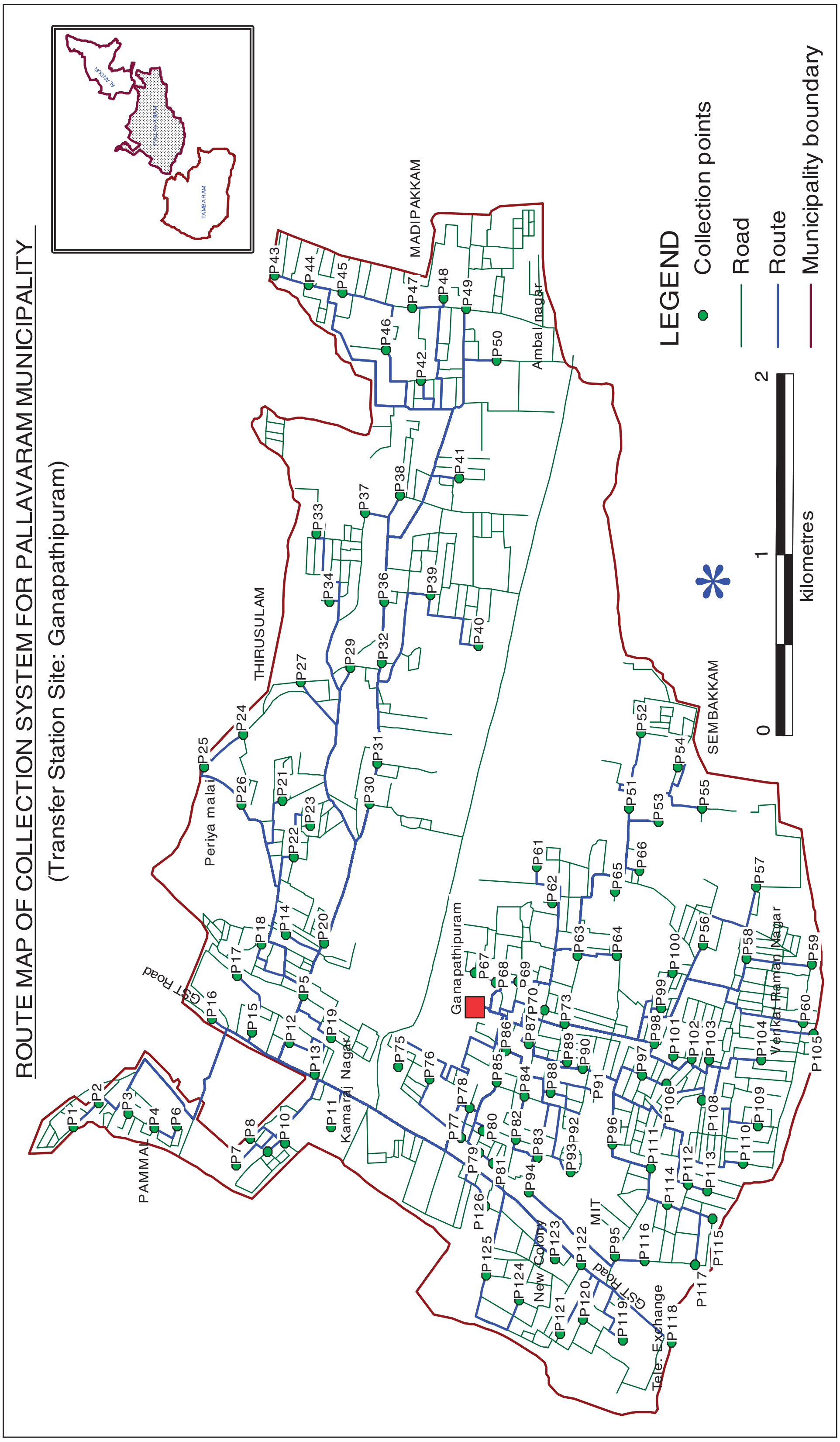

Figure 5. Route map of primary waste collection in Pallavarapuram municipality.

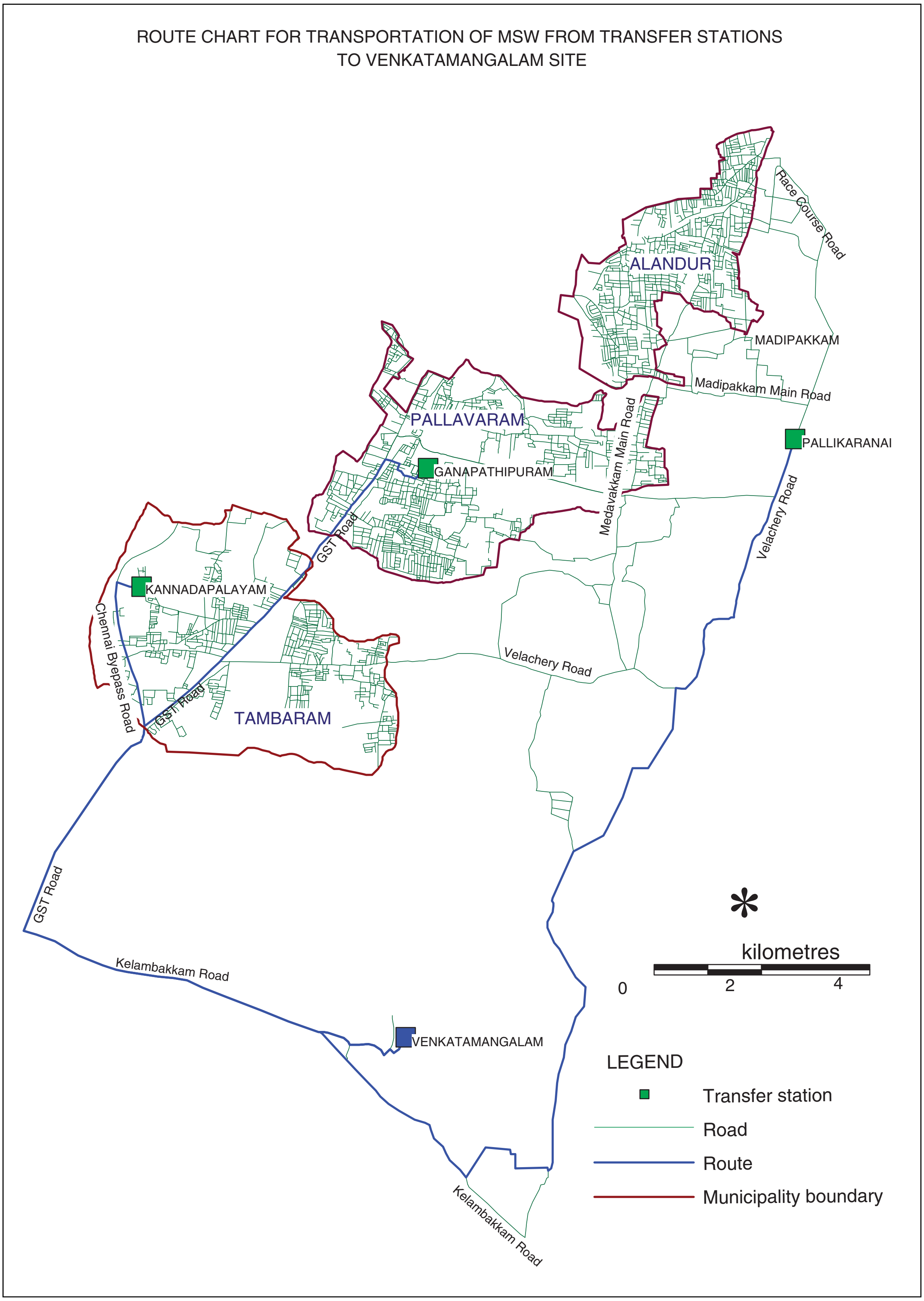

Figure 6. Route map of secondary waste collection in Pallavapuram municipality.

the bin or transfer station and sends the positional data received from the SMS to the internet server. This software can be modified to show each vehicle on a map in the control station, send diagnostic messages to the vehicle unit and even send commands to immobilize the vehicle. The web server software plots the position of the vehicle on a GIS map and enables anyone with a userid and password to login and view the current location of the vehicle. There is an option to view the progress of the vehicle on the entire route. The standard data displayed is position, direction and speed.

In the experiment that was planned, the GPS was fitted to a dumper vehicle which would collect the position, time and speed (of the vehicle) data. The GPS receiver would be a 5 m EI lab GPS and the GIS software would be TDOx VTU designed specifically to store, display, manage, and analyse transportation data The differential GPS data was obtained from the cellular tower at the municipal office and after collecting the data, it was linearly referenced in the ARCGIS-generated map in Figures 5 and 6. The GPS component captured date, time and latitude/longitude data whereas the trip start and end times were passive data elements to the respondent. The advantage of passive data recording is that the respondent burden is minimized and the travel times and distances that are collected represent the true picture about the length and duration of the trip. The linearly referenced data can be displayed either on the already existing map or can be used to create a new network. The current vehicle location is displayed as a banner on the page. Clicking on the vehicle number displays a municipal map and puts the vehicle position on that map.

Transfer station

A material recovery facility (MRF) could be established in the proposed transfer stations in each municipality and a semi-mechanized system with handpicking-off-the-belt established. Rag pickers or scavengers could be employed for the sorting and selling of the recyclable waste. The transfer station would be provided with a material receiving area, hopper, manual sorting area, trommel screen, organic material storage area and conveyors.

Design of in-vessel composting system for biodegradable waste

Each module is best described as an in-vessel composting system which consists of the following components as in Figure 7.

1. Raw material storage area (storage pits for bio-degradable waste and wood chips).

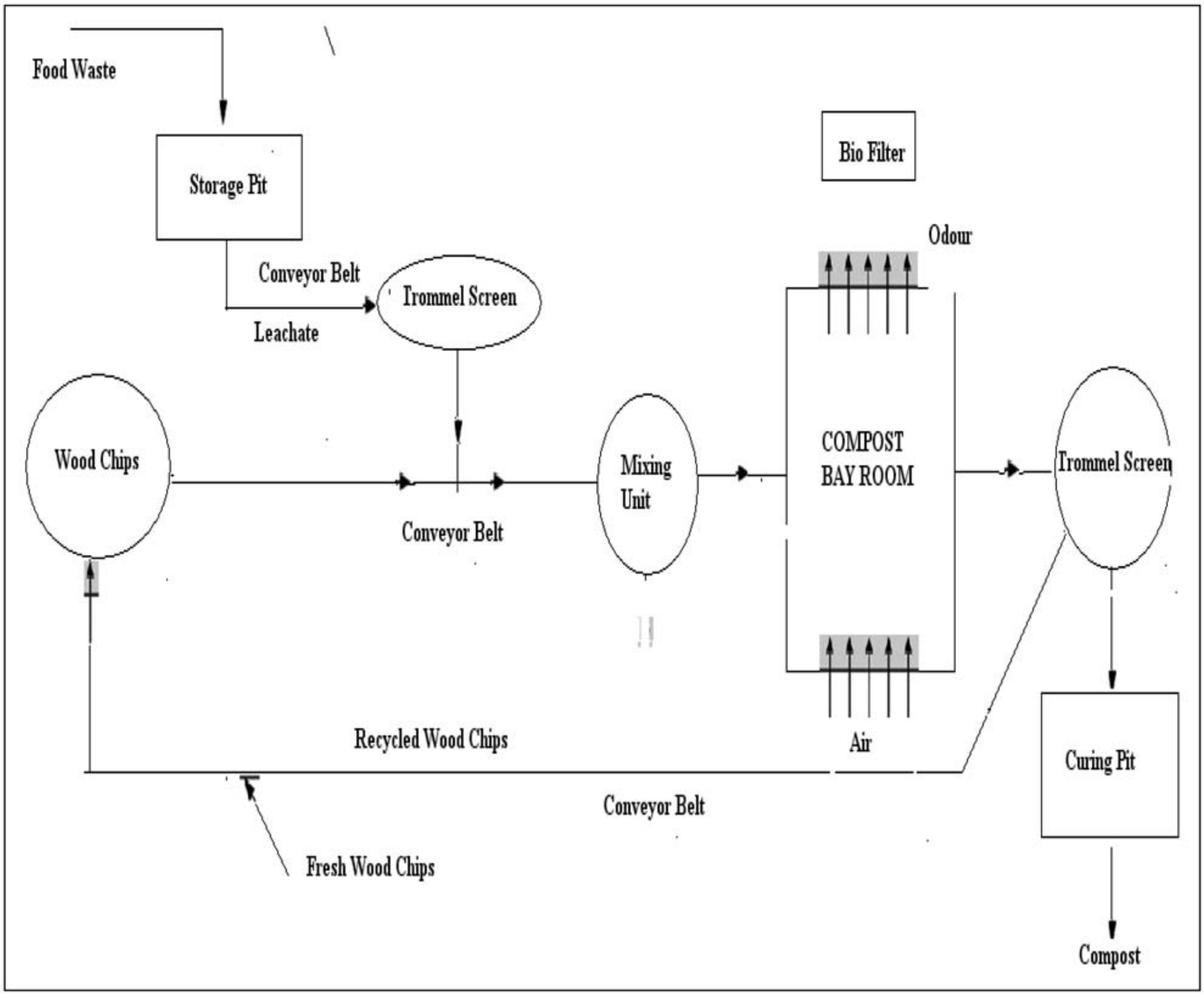

Figure 7. Components of in-vessel composting unit.

2. A mixer/blender to prepare a homogeneous blend of organic materials.
3. Sixty concrete channels: 60 m in length, 5 m in width and 2 m high.
4. Positive aeration system (tubes) in channel floors and a leachate collection system in the channel floors with centrifugal blowers equipped with timers to oxygenate the biomass.
5. Compost turners equipped with cross-conveyor transfer systems in each unit and a transfer carriage for the compost turners.
6. Curing pit and storing pit.

This facility is designed to function in an intermittent flow operation. Fresh organic material arriving daily, after processing from material recovery area would be fed into a heavy-duty bio-shredder to produce an MSW particle size of 0.025 m. Wood chips of size 0.05 m would be stored in stainless steel bins on the other side. A weighed quantity of the waste and wood chips would be mixed together in the compost mixer through a chute. The mixer would move to the first channel to transfer them into the channel by compost turner.

The method of operation within the facility includes the following processes. Composting takes place between walls that form long narrow channels. A rail on top of each wall supports and guides a compost-turning machine to move the materials towards the end of the bed. The first channel contains the organic material loaded on a single day. The material is turned mechanically by the compost turner creating a homogeneous blend. The material progresses throughout in the channel creating a residency time of up to 60 days. As the spent compost is removed from the channel, it will be transferred onto a belt conveyor to the trommel screen to separate wood chips. The compost produced is transferred onto a belt conveyor and moved to the compost curing pit. The first channel will be refilled with incoming materials after 60 days. In a similar way subsequent channels would be filled. While the material is in residence, it is sufficiently aerated through the floor aeration system to promote very active and accelerated decomposition. Air flow into the mass are regulated with timers on the fans. Any leachate from the biomass enters a leachate collection system for redistribution onto the biomass later. The wood chips separated from compost are sent to the bin for storage. Moisture can be controlled by pumping leachate and fresh water through a spray-bar positioned in the roof of the tunnel onto material being processed.

Cost and expenditure

Being a public utility and an essential service, investment in solid waste management does not require justification in terms of positive return on investment or minimum profits. Such an investment, however, needs to be justified on the basis of being the technologically feasible option for achieving the required degree of efficiency with the least cost.

The total cost for the newly designed collection systems was estimated to be around US$ 420, 000 for the fixed cost of storage bins, dumper bins and collection vehicles as in Table 10. Disposal cost can be defined as total cost incurred by the municipality in disposing of the MSW and accordingly, the estimated fixed and operating cost for solid waste management were obtained.

The sources of financial contributions for the project are the centre, state government and tax collected by the municipality. It was calculated that US$ 2.4 per capita per day needs to be spent as shown in Table 10. All the project

Table 10. Investment costs of collection system for Pallavapuram (US$)*

Sl. no	Description	Available	Required	Unit price	Total cost
1	Providing 2 bins for segregation of waste to each households	–	37 860 × 2 (As on 20/08/2008)	0.41	31 045
2	Tricycles	38	102	62.04	6 328
3	Tricycles bins		920	4.16	3 827
3	Dumper bins	–	80	208	16 640
4	Dumper placer vehicles	3	2	16 642	33 284
5	Bulk refuse carrier	–	2	31 204	62 408
6	Civil works for transfer stations	–			164 344
7	Machinery and equipment for transfer stations	–			112 336
	Total				
			As on 21/08/2009	US$ 1 = Rs 48.07	US$ 417 556
	Grand total of investment and operation cost				US$ 420 754
	Expenditure per capita		US$ 420 754/177070		US$ 2.4 day^{-1}

Table 11. Operation and maintenance of collection system for Pallavapuram

Sl. no	Description	Available	Unit price day^{-1}	Total cost
1	Primary collection			
	Source segregation			
	Manual workers	400	US$ 2 per worker	US$ 800
	Tricycle maintenance	140	US$ 1	US$ 140
2	Secondary collection			
	Dumper placers			
	Fuel charges	61 trips day^{-1} × 30 L diesel trip^{-1}	US$ 1 L^{-1}	US$ 1830
	Maintenance and depreciation	US$ 6 day^{-1}		US$ 6
	Salary and other expenses	US 3 day−1		US$ 3
3	Bulk refuse carrier			
	Fuel charges	5 trips day^{-1} × 2 Nos × 30 L diesel trip^{-1}	US$ 1 L^{-1}	US$ 300
	Maintenance and depreciation	US$ 11 day^{-1}		US$ 11
	Salary and other expenses	US$ 2.5 day^{-1}		US$ 2.5
3	Tipper			
	Fuel charges	5 trips day^{-1} × 1 Nos × 20 L diesel trip^{-1}	US$ 1 L^{-1}	US$ 100
	Maintenance and depreciation	US$ 3.5 day^{-1}		US$ 3.5
	Salary and other expenses	US$ 2.5 day^{-1}		US$ 2.5
			Total	US$ 3198 day^{-1}
				US$ 0.003 million per day^{-1}

components are to be funded by these sources. It is estimated from the municipal authorities that the property tax amounts to US$ 0.36 million in 2006 in which 30% could be accounted for by a sanitation tax that could be used for operation and maintenance cost (US$ 0.003 million day^{-1}) as in Table 11. For the door-to-door collection of waste, it is recommended that private parties should be involved on a fixed rate per unit quantity of waste collected. Public–private partnership is recommended on Build Operate and Transfer basis for the operation and maintenance of compost plant. The investment cost is estimated at around US$ 9.2 million for the construction of the in-vessel units (PMC 2008). It is expected that the plant will produce 30% compost out of 250 Mtonnes amounting to 75 Mtonnes day^{-1} in the first year of its operation. The selling price of the compost was assumed to be US$ 41 Mtonnes^{-1}, with an annual output totalling approximately 22 000 Mtonnes year^{-1} and a projected revenue of US$ 9.5 million year^{-1} offset against the investment cost in 10.5 years.

Conclusion

In the present study, an attempt was made to design and develop an appropriate storage and collection plan for the Pallavapuram municipality corporation of Tamil Nadu, India. The model proposed was designed to plan the allocation of waste bins and a route network using GIS and VTU for the study area. In the proposed system, leachate is to be contained within the HCS recommended and should not leak from the container which would prevent littering of waste during transportation. Furthermore the HCS containers are easy to clean and maintain and also look better than SCS (Naresh Kumar and Sudha Goel 2009). The movable containers to be used in the proposed system have a total capacity of 2.5 m^3 with hydraulic loading/unloading attachments. The waste collected by the tricycle carts is to be unloaded directly into the respective chambers of the bins. The labour requirement is also less than in the existing system (one driver and one cleaner required in HCS in comparison with one driver and five to six collection labourer in SCS).

A GIS-based optimal routing model was used to develop an optimal route map for efficient transport system. This was carried out, based on parameters such as population density, waste generation capacity, road network, storage bins and collection vehicles, etc. The developed route map can be used to trace the minimum distance as well as efficient collection paths for transporting the solid waste from collection points to final disposal site through transfer stations. The data obtained from ArcGIS maps can be used for the retrieval, update and visualization of the information required. The produced maps can provide municipal authorities, environmental engineers and decision-makers with data about the present waste management system which can be used for the improvement of the existing system and for future planning. The municipality should be ready to implement bye laws prohibiting littering of waste on the streets and directing citizens to store the waste generated at source in two bins. The municipality can provide two bins for every household, purchase tricycles, bins and vehicles required for primary and secondary collection with the financial assistance by the Government. The primary collection can be started as per the present proposed system with the help of municipal sanitary staffs after the transfer station construction. At present a part of the Ganapathipuram burial ground has been used as a dumping yard. Once the construction works in the final disposal site are finished, the secondary transportation of waste can be followed. Expenditure incurred in the proposed system of solid waste management will be much less than the existing system. It is estimated that there will be roughly 30% cost-saving in this new approach. The number of vehicles to be maintained in the proposed system is very much less (PMC, 2008). In the existing system it is very essential to correlate vehicle and manpower for removal of garbage, but in the proposed system even in the absence of a vehicle, garbage could be swept and collected in the dumper bin. Hence the vehicle movement becomes independent of sweeping and collection of garbage. The proposed model can be used as a decision-support tool by the municipal authorities for efficient management of the daily operations for moving solid waste, load balancing within vehicles, managing fuel consumption and generating work schedules for the workers and vehicles.

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