OPTIMIZATION OF SOLID WASTE COLLECTION AND TRANSPORTATION ROUTE IN PHUENTSHOLING CITY USING GIS

Dawa Zam[1], Sangay Jamtsho[2], Tshering Dema[3], and Jhulen Chettri[4], Chimi Wangmo[5]

Department of Civil Engineering, College of Science and Technology
[1]2009013@cst.edu.bt, [2]2009107@cst.edu.bt, [3]2009079@cst.edu.bt, [4]20710@cst.edu.bt, [5]cwangmo@cst.edu.bt

ABSTRACT

The disposal of wastes without proper collection system leads to health hazards, economic loss, and environmental sufferings. An effective solid waste management system includes an optimized routing system for collection and transport of solid wastes. This paper describes the use of GIS to optimize solid waste collection and routing system and introduces integration of segregation for Phuentsholing Municipality. The study uses information gathered through questionnaires, waste generation rate, location and volume of storage bins, collection vehicles, etc. The suggestions for amendments in the system through the study would exhibit remedies for solid waste management problems like adoption of segregation, proper allocation of waste bins and its proximity convenience, proper collection and route schedule.

Keywords: Solid Waste, Collection Routing, Transfer station, segregation, GIS

1. INTRODUCTION

Located at geographical coordinates of 26° 51'N 89° 23' E, Phuentsholing city is a major gateway into Bhutan and it operates as the nerve center for economic and commercial activities. As our nation geared towards development, this town gradually increased both in terms of importance and inhabitants. The population data collected in 2003 estimated a population of 26000 with a growth rate of approximately 7% per annum. The increase of population in the city has increased the amount of waste generation and the need for a proper waste

management system is the call of the hour to ensure a sustainable and secure future.

Solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes in the manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental

considerations, and that is also responsive to public attitudes. Solid wastes comprise of all the wastes arising from human and animal activities that are normally solid and that are discarded as useless or unwanted. Due to the industrialization, urbanization, uncontrolled urban sprawl, improvement of living conditions and population growth, Solid Waste Management has become a monumental problem all over the world. Studies carried out by Visvanathan et al., in 2001 shows that in Asia waste disposal is a serious problem due to uncontrolled and unmonitored urbanization, and lack of financial and human resources trained in Solid Waste Management system. As per the national survey on solid waste conducted during November 2007 and January 2008, average waste generation has been estimated as 0.533 kg/person/day in Phuentsholing.

1.2 OBJECTIVES OF THE STUDY

The main objective of the study is to integrate and optimize the solid waste collection system and collection routes in Phuentsholing City using GIS. The sub-objectives are as listed below:

- To study the current waste collection process; its shortcomings and propose improvement to the system.
- To work out proper allocation or reallocation of green and non-green bins in terms of proximity convenience of the users and ease of collection by the concerned authorities.
- To fix route and schedule for each collection vehicle and schedule different collection timing for green and non-green wastes. Green waste might need to be collected every day in hot and humid climate such as Phuentsholing.

- To study the feasibility of usage of community bins instead of door to door collection and need for additional community bins to supplement current number of bins.
- To study the feasibility and need for a transfer station where non-green wastes can be further segregated into recyclables and non-recyclables.
- To maximize the collection coverage with focus on fuel efficiency improvement.

2. BACKGROUND STUDY

The present system of waste collection in Phuentsholing city follows an uncoordinated routine and schedule, and this has given rise to an unhygienic living environment, discomfort to the residents and an uneconomic collection system in the city. Due to the lack of segregation practices, all types of waste produced are mixed and disposed in single bins leading to the filling up of provided bins within a short period of time. Collection vehicles are sent to collect wastes from different areas in a random manner making it ineffective. Phuentsholing city is divided in three zones for ease of operation. In the zone 1 which mainly comprises of core area, collection & transportation takes place every day including Sundays. In other two zones frequency is four times a week or once in two days. Official timings for the waste collection are 6.30 AM to 5 PM. Each vehicle makes two trips per day,

one each in two shifts. 4-5 waste collectors are deputed with each vehicle for collecting waste from the generators bins and for assisting operator. The vehicles have no compartments to collect different type of waste, and entire waste is collected in mixed form .Waste collectors who collect and sell recyclable products, have to sort

out and put in different sacks before operating compaction system of the vehicle. In this process, substantial time is lost. No separate provision for primary collection either from bulk generators like commercial complexes, multi-stored residential units, Hotels and Restaurants, institutions, fruit and vegetable yard and from producers of construction, horticulture, biomedical, electronic and industrial waste are in place. The current system also presents potential health hazard to the waste collectors as all type of wastes including hospital and residential wastes are disposed to a common storage bin. The fleet of vehicles is not optimally used. Every vehicle is made to make two trips everyday but waste quantity is hardly sufficient even for one trip. Transport vehicles do not follow scheduled route and sometimes double handling of waste becomes inevitable. Waste collection and transportation is done in three stages by three groups of workers. A separate group of workers are engaged for collection of swept material and transporting to community collection points with of sacks. The third group of workers is assigned along vehicles to collect waste from communal and private bins. 2 tippers and 3 compactors are available for block collection and transportation of waste to the disposal place. The vehicle collect and unload the bin one by one and thereafter the vehicle moves to the next stoppage and finally to the landfill site for final disposal. No norm is followed while deciding the capacity and placing of community bins, due to which some bins/pits remain overflowing and few remain empty.

2.2 DATA COLLECTION AND ANALYSIS

Primary data was collected in three forms; Landfill data, Questionnaire data and Onsite survey.

3.1 LANDFILL DATA

Landfill data was collected from the landfill site located at Toribari with close monitoring of the amount of waste brought from different areas of the city for a period of one week. This was done to garner a general idea on the amount of waste produced from different areas for cross-checking with the onsite survey data.

Table 1 Waste collected from main town area

Number of trucks							
Time	Mon	Tue	Wd	Th	Fri	St	Sun
7-11am	1	1	1	1	1	1	1
1-5 pm	1	3/4	1/2	3/4	1/2	1	1

Table 2 Waste collected data from Pemaling, Army camp, BOB, RICB, Old hospital, PWD colony, Bank colony, CST

Number of trucks							
Time	Mon	Tue	Wd	Thu	Fri	St	Sun
7-11am	1	1	1	1	1	1	1
1-5 pm	1	1	3/4	3/4	3/4	3/4	1

Table 3 Waste collected data from NPPF colony, PHSS, Torsa riverside, Sabji bazaar

Number of trucks							
Time	Mon	Tue	Wd	Thu	Fri	St	Sun
7-11 am	1	1	1	1	1	1	1
1-5 pm	1	3/4	1	1	3/4	1	1

Table 4 Waste data collected from Kabreytar, Peepaldara, Damdhara, Pepsi factory, Hospital area

Number of trucks							
Time	Mon	Tue	Wd	Thu	Fri	St	Sun
7-11 am	1	0	1	0	1	0	1
1-5 pm	0	1	0	0	1	1	0

3.2 QUESTIONNAIRE DATA

A questionnaire survey was carried out at 100 households at different areas of the city to understand both the present collection system to get public input on the kind of collection they desired. The following charts show their responses.
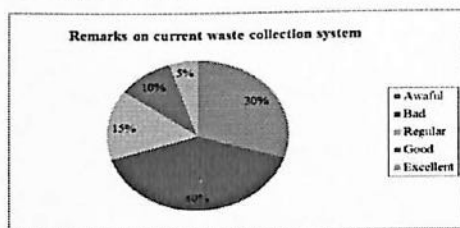

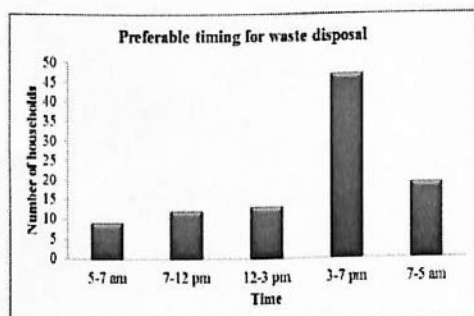**Fig. 1** Remarks on the current waste management system

Fig. 2 Preferred disposal timing
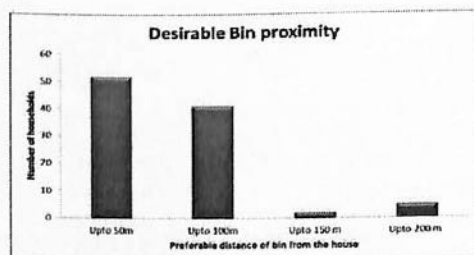
Fig. 3 Frequency of collection desired
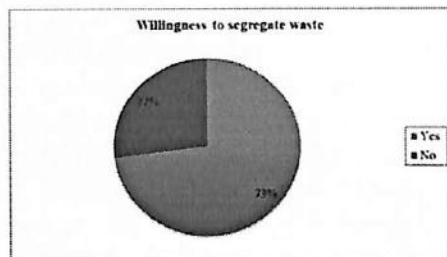

Fig.4 Preferred bin proximity

Fig. 5 Willingness to segregate at source

3.3 ON-SITE SURVEY

On-site survey was carried out for few days by studying various aspects of the present collection system including routes followed, speed and time of collection, location of bins etc.

A. PROBLEMS ASSOCIATED WITH THE EXISTING SYSTEM

The onsite survey carried out helped understand some of the problems with the current system. During the survey the problems were noted and analyzed later. The remedies of the problems were used as a foundation for the design of new collection system.

B. UNEVEN DISTRIBUTION OF BINS

The existing bins are not evenly distributed for entire collection of MSW. Due to the uneven distribution, there is an inconvenience for the residents to drop their MSW in the collection bin. This ultimately leads to more dumping of MSW in the drainage and along the road side.

C. INADEQUATE SIZE OF DUSTBINS

No norm has been followed while deciding the capacity and placing of community bins, due to which some bins/pits remain overflowing and few remain empty. The trash collector has to visit twice for the same collection point which leads to consumption of more time for the waste

collection and thus leading to consumption of more fuel and operation cost of vehicle. Some of the bins are seen overflowing and the waste are scattered around the bins thus causing unhealthy surrounding. Some concrete community bins are distorted as in case of bin near the army camp, some bins along the Samdrup lam leading to scattering of waste around the bins.

D. TIMING OF THE COLLECTION

Due to no fixed collection timing, door-to-door collection system takes a lot of time having to wait for people to come and throw their wastes. The collection time is further increased with repeated visits to the same vicinity due to people not turning up to throw their wastes on time. The collection timing being carried out at peak hours of traffic flow causes problems for both waste collection vehicles and other road users. Also, since Sunday is off, the collection on Monday is hectic with community bins overflowing.

E. PARKING PROBLEM

Since most of the dustbins are placed along the road, it is difficult and tedious for the waste collectors to collect and put in the trash vehicle if other cars are parked near the dustbins during the collection time. Thus it leads to delay in collection time. No allocation of fixed parking space leads to random parking and consequently, traffic jams.

F. NO PROPER SEGREGATION

Segregation is limited to few of the laborers picking up some plastic bottles and cardboards for sale. No revenue is generated by the city corporation from the sale of these items. The remaining wastes are directly dumped at the landfill site.

G. COLLECTION VEHICLE NOT OPTIMALLY USED

Collection vehicle collects wastes in two shifts. Since collection is haphazard, sometimes vehicle gets filled up before the bins in its areas are emptied while at other times, the vehicle goes to dumping yard with its loading bay half full. When certain bins are left out due to the collection vehicle being full, some other vehicle is asked to empty them resulting inefficient vehicle usage and increased collection time taken.

3. PROPOSED COLLECTION SYSTEM

The city was divided into 4 zones in accordance to the waste production as listed below.
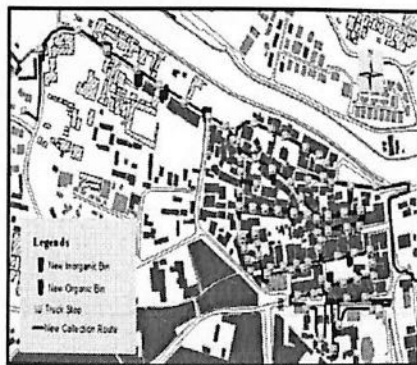
4.1 PROPOSED COLLECTION SYSTEM FOR ZONE 1

Fig. 6 Proposed collection route and bin location.

Multiple visits to the same vicinity and door-to-door collection system in the present system has been done away with in favor is placement of new community bins at places where adequate space is available and provision of two building bins for organic (180 lit) and inorganic (360) waste storage at each building. Temporary waste truck stops have been illustrated in the

map. The collection time required has been kept as 5 minutes for emptying community bins and 3 minutes for building bins. The time required for entire shift has been calculated by assuming collection time and speed of vehicle. Due to traffic jams caused by day time collection in the present system, night time collection is being proposed for this zone. The collection schedule and comparative analysis between the present and proposed system is tabulated below.

**Table 3** Zone 1 collection schedule

Day	Organic (9pm-2am)	Inorganic (9pm-2am)
Mon	•	
Tue	•	•
Wed	•	
Thu	•	
Fri	•	•
Sat	•	
Sun	•	•

Table 4 Zone 1- Comparative analysis between the present and proposed system.

Criteria	Old route	New route	% eff
Distance travelled in a week	347.9km	245 km	29.57

Time taken for collection in a week	52.5 hours	37.5 hours	28.57
Fuel consumption in a week	105 liters	75 liters	28.57
Fuel cost per week	Nu.4861.5	Nu. 3472.5	28.57

3.2 PROPOSED COLLECTION SYSTEM FOR ZONE 2
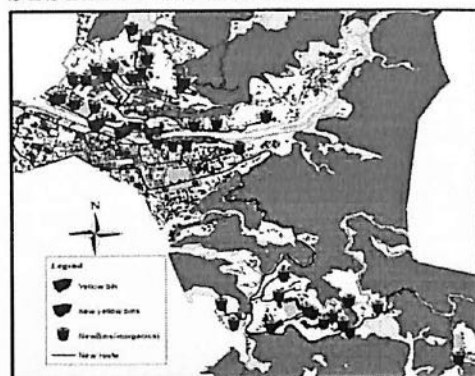
Fig. 7 Proposed collection route and bin location.

New community bins have been provided at desired proximity of 50-100m of the users. Two bins at each location for organic and inorganic waste collection have been provided. The comparative analysis between the present collection systems is tabulated below

Table 5 Zone 2- Comparative analysis between the present and proposed system.

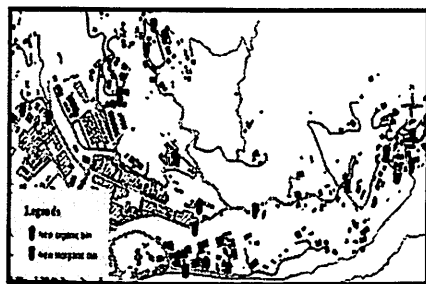| Criteria	Old route	New route	% eff
Distance travelled in a week	350.7km	218 km	37.8
Time taken for collection in a week	56 hours	32.2 hours	42.5
Fuel consumption in a week	105 liters	75 liters	28.57
Fuel cost per week	Nu.4861.5	Nu. 3472.5	28.57

3.3 PROPOSED COLLECTION SYSTEM FOR ZONE 3

Fig. 8 Proposed collection route and bin location.

New community bins have been proposed at areas where door-to-door collection system is in place. Also, collection will start from the furthest point or from places of higher elevation to improve fuel efficiency.

Table 6 Zone 3- Comparative analysis between the present and proposed system

Criteria	Old route	New route	% eff
Distance travelled in a week	282.52 km	213.35 km	24.5
Time taken for collection in a week	56 hours	38.5 hours	31.25
Fuel consumption in a week	105 liters	72.2 liters	31.23
Fuel cost per week	4861.5	3342.9	31.23

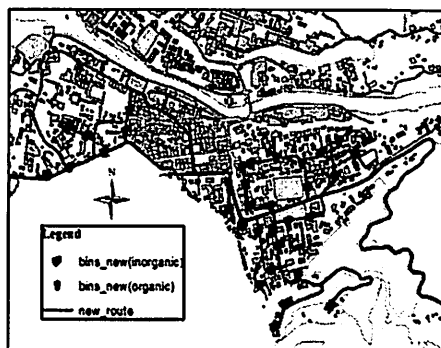## 3.4 PROPOSED COLLECTION SYSTEM FOR ZONE 1

Fig. 9 Proposed collection route and bin location.

In this zone, new community bins have been proposed at areas where door-to-door collection system is in place at proximity of 50-100m of the users. Two bins at each location for organic and inorganic waste collection have been provided. The comparative analysis between the present collection systems is tabulated below

Table 7 Zone 4- Comparative analysis between the present and proposed system.

Criteria	Old route	New route	% eff
Distance travelled in a week	277.2 km	106 km	24.5
Time taken for collection in a week	56 hours	44.2 hours	21.07
Fuel consumption in a week	54.44litres	21.2 liters	61.1
Fuel cost per week	2521	982	61.1

4. TRANSFER STATION

The proposed collection system has a transfer station located at Zhung Lam above the Army Guest house. The purpose of this transfer station is to store all the inorganic wastes and segregate recyclables from the other wastes. Recyclables would be sold to markets to generate funds and

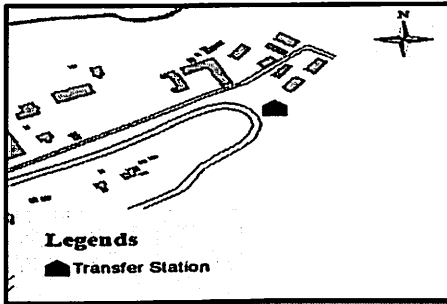other wastes would be dumped to the landfill.

Fig. 10 Location of transfer station.

5. CONCLUSION & RECOMMENDATION

The population of Phuentsholing City is increasing rapidly leading to an increase in the amount of waste generation and associated impacts. Application of geographic information system for monitoring the accumulation of waste, segregation at the source, collection, and transportation to the disposal sites through a comprehensive assessment of the layout of the city, peak traffic flows, and municipal services provided helps to create a comfortable and environmentally safe living environment for the citizens. The project was undertaken for improving the solid waste collection system in Phuentsholing city based on route optimization and segregation of wastes. Door-to-door collection system was replaced by the provision of community bins. The calculation of the adequate volume of new bins was done using the waste generation rate multiplied by approximate population figure in the locality. The volume of new bins was fixed keeping in mind the interval of collection for the wastes- daily for organic wastes and thrice a week collection of inorganic wastes. The result indicates that the application of GIS optimizes Solid Waste Management in terms of collection time reduction and distance travelled. These savings are highly related to fuel consumption. The study demonstrates the value of GIS technology as a waste collection optimization tool which provides an alternative method of minimizing operational costs of the collection vehicles.

The project also includes the segregation component of integrated solid waste management. The segregation of waste at source and promotion of recycling or reuse of segregated materials reduces the quantity of waste and the burden on landfills. The location of transfer station has been identified considering factors such as ideal location for all the four trucks for dumping inorganic wastes, availability of adequate space and proximity convenience to the market where recyclables can be sold off generating revenue for the municipal body. There are a couple of recommendations in regard to this topic.

- There may arise difficulties in the implementation of this proposed collection system, particularly due to the lack of coordination between municipality, non-governmental organizations, private sector waste collectors and local residents. Improving coordination is a key to improve waste collection systems and data sharing, through which it is hoped greater financial support can be generated.

- The project proposes both allocation of new bins at places deemed necessary and re-use of the old bins if its location is ideal. For places where old bins are to be continued in use, certain maintenance work like patching up and repainting is required.

- Appropriate tools in adequate numbers such as shovels, spades, waste carrying baskets etc. should be provided to the workers.
- The added longevity/lifespan of the present landfill at Toribari can to be studied now that segregation facility is being introduced.
- Other components of solid waste management like location and management of new landfill site, transfer stations etc. can be analyzed using GIS.
- Further research needs to be carried out regarding the size and functionality of the proposed transfer station. The revenue generated from the sale of recyclables amounts to a considerable sum. Therefore a thorough study on establishment of recycling units may be carried out.

REFERENCES

Chang, N., Lu, H. Y., & Wei, Y. L. (1997). *GIS Technology for Vehicle Routing and Scheduling in Solid Waste Collection Systems.* Journal of Enviromental Engineering , 901-910.

Garg, S. (2010). *Seweage Disposal and Air Pollution Engineering. In S. Garg, Disposal of Municipal and Industrial Solid Wastes* (pp. 598-601). New Delhi: Khanna Publishers.

Ghose, M. K., Dikshit, A. K., & Sharma, S. K. (2006). *A Gis based transportation model for solid waste disposal-a case study of Asansol Municipility. Waste management* , Vol. 26, 1287-1293.

Indeglia, P. (2006*). Optimized Solid Waste Collection System for Kratovo, Macedonia.* University of Florida,Department of Environmental Engineering Sciences (pp. 4-13). Capstone Design.

Jain, P. (2011). *Minimizing cost for Municipal residential solid waste collection in City of Newark using Goal Programming & GIS tools.* In K. D. Messer (Ed.), Department of Food and Resource Economics • College of Agriculture and Natural Resources • University of Delaware. (302) 831-1316, pp. 9-18.

Kursh, S. J., & Bodin, D. L. (1978). *A Computer-Assisted System for the Routing and Scheduling of street sweepers.* operations Research , 525-537.

Matter, A., Dietschi, M., & Zurbrugg, C. (2012). *Improving the informal recycling sector through segregation of waste in the household.* Swiss Federal Institute of Aquatic Science and Technology , 4-6.

Mufeed Sharholy,Kafeel Ahmad,R.C. Vaishya,R.D. Gupta. (2006). *Municipal solid waste characteristics and management in Allahabad,* India. 495.

OGWUELEKA, T. (2009, june). *Route optimization for solid waste collection: Onitsha (Nigeria) case study.* J. Appl. Sci. Environ. Manage. Vol. 13(2) , 37 - 40.

Samarakoon, L. (2009). *Locating Bins using GIS. International Journal of Engineering & Technology* IJET-IJENS Vol: 10 No: 02 , 97-109.

UNCHS, U. N. (1994). *Promotion of Solid Waste Recycling and Reuse in the Developing Countries of Asia.*

Upadhyay, v., S, J. A., & P, P. M. (march 2012). *Solid Waste Collection and Segregation: A Case study of MNIT campus, Jaipur.* International Journal of Engineering and Innovative Technology (IJEIT) , 144-145.

Vijay, R., Gupta, A., Kalamdhad, A. S., & Devotta, S. (2005). *Estimation and allocation of solid waste to bin through geographic information systems.* Waste management and Research , 479-484.