GIS AND SOLID WASTE COLLECTION MODELING: DEVELOPING A DATABASE FOR MULTI CRITERIA WASTE COLLECTION OPTIMIZATION IN MALAYSIA

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Introduction

Though the application of computer technology and the geographical information system in the urban and environment planning departments of Malaysia is wide spread and has generally been acknowledged by professional to have proven effect in extensive data processing and management, analysis and contributions in some form decision making, solid waste management department and agencies in the country have been slow at inducting this powerful technology in their work. Some studies have been carried out using GIS to identify possible suitable location for landfills. In certain case waste management soft wares have been introduced and tried with mixed successes, the fact is that these technologies do not address the particularly local situation of waste collection problem in the country. Data on waste production and collection is not properly documented and increasingly complicated area road networks that are not documented make accessibility planning difficulty.

Objectives of the Waste Collection Optimization Study

The past two decades of economic growth in the country has seen a rapid transformation of the urban environmental landscape. There has been tremendous development in housing and infrastructure; road linkages are grossly improved presenting a complex mesh of road networks. Health and environmental consideration has met waste disposal site are being located away from urban areas. Cost of waste collection has increased as a consequence causing the government to privatize waste management. The situation faced by waste management is how to develop a system, which not only curtails the increasing cost, but also provide timely and efficient solid waste collection process. To explore possibilities of other disposal methods recycling and composting and reducing the heavy dependence landfill.

The study is carried out to develop a GIS base model for optimizing residential waste collection in Petaling Jaya. It is to explore parameters to help systematize the collection process making it possible to quantify and predict waste on offer for collection by type and composition. Efficient routes are worked out based on the Traveling Salesman Algorithm to optimize residential street-to-street collection linkages and to disposal site. Provisions are made for easy identification of areas of potentially high production of different waste streams to allow the development other environmental friendly disposal methods such as composting and recycling. The collection optimization process emphasis cost reduction, timely collection schedule, distance reduction based on efficient routing and networking, and resource allocation in terms of distribution and location of storage containers and the dispatch of collection vehicles to collection areas.

Waste Collection in Petaling Jaya

Petaling Jaya municipality is located to the west of Kuala Lumpur covering an area 162 sq. km. It has had a sturdy growth socio-economy and physical development over the years attracting population growth rate of 1.5 and presently estimated to be about 474,100. It enjoys an averagely higher

standard of living than other neighboring municipalities. Waste management was the responsibility of the local council, Majlis Perbandaran Petaling Jaya (MPPJ) but increasing cost and the need to improve services has resulted in privatization. For the new waste Management Company Alam Flora (AFSB) that has inherited a system lacking collected data, paramount task is to build a database and systematize the residential collection process. The urban dynamics, complex roads and street network and the mixed socio-economic nature of the residential housing present a challenge

The solid waste collection and management in Petaling Jaya presented these problems the increasing cost of collection and disposal, complex and extensive road network needed to be covered thus affecting time and cost in the collection process, haphazard planning without a clearly identified routing, waste and inefficient utilization of limited resources, limited use of computer and information technology in the waste management process making it difficult to integrate it with the overall urban planning strategy. With these problems in mind the study seeks to restructure and organize the solid waste management process such that community waste could be collected and dispose off at a minimal cost while ensuring efficiency to preserve public health and environment. It also provides for the identification and separation of waste to allow for the development composting and recycling to reduce the over dependence on landfill for disposal.

Residential Waste Collection Modeling

A model is developed to simulate various management scenarios based on calculations, statistics and graphical data on the study area and to be integrated with the geographical information system. The model comprises supporting sub-models, the waste production and prediction sub-model and route generation sub-model. The factors identifies as influencing the waste collection process are

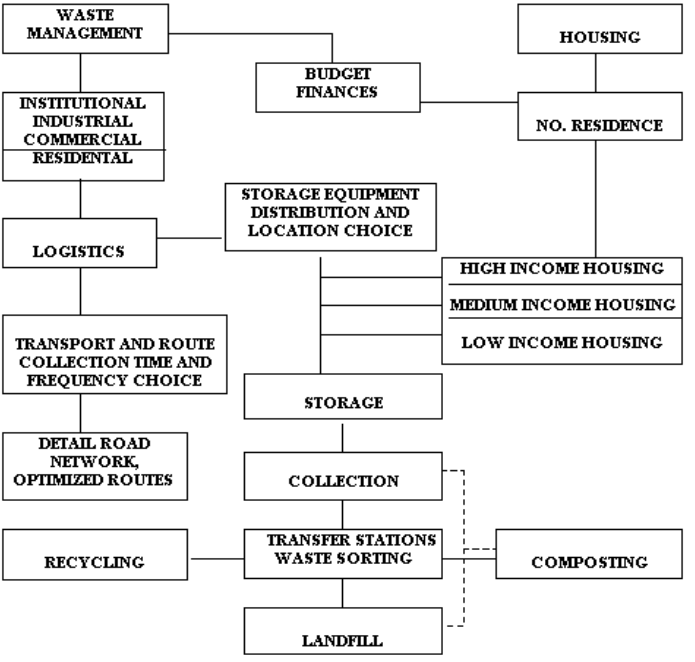
- Cost of waste collection
- Logistics/ facilities for collection
- Waste generation/ production
- Routes for waste collection
- Time and distance travel from collection to disposal
- Frequency of waste collection

The waste prediction sub-model is to help identify and determine the quantity and of waste expected for collection. It includes: a) Waste generation, this is determined based on data on quantity and income levels. b) Waste production: calculated on per capital waste generation in relation to number of housing units and household size. c) Waste type: assessed on data on housing units of different income levels, schools, industries, commercial areas and hospital.

The route generation sub-model determines the various routing options; this involves a) Trip generation determining the origin, destination and also the entry and exists of each collection area and the number of stops to the disposal site. b) Calculation of travel time: based on costs and trips based on distance and speed data. c) Accessibility scan: road links, one-way traffic and congestion, road type and class and other accessibility indicators.

The model is an important component of the planning process and used as part of the analysis of the waste collection, It describes the choices available for resource allocation, waste to be collected and the optimize routes to be plied, the relevant information are used for planning and decision making. The model is to estimate the quantity of waste to be expected for collection in the area and building by type and composition base on the calculated number of residence. This allows management to determine the number of storage container and collection trucks required for the area. The road network has optimize collection routes worked out based the traveling salesman algorithm taking into consideration accessibility, traffic congestion and the width of the roads. Costs, time and distance travel by trucks are determine from operation depot to collection areas and to disposal

Figure 1. Conceptual Model for Residential Waste Collection Modeling

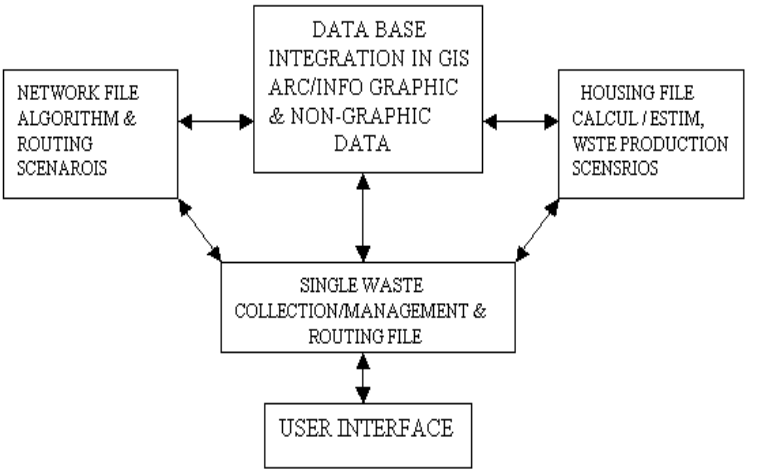


.Finances and the budget for waste collection and management are paid to the private Management Company by the local council but it is expected that direct service charge will be introduce in the future. The model make it possible to work out and determine the cost required for effective operation and the amount to be collected from residence.

The waste collection GIS presents a centralized database for storage and retrieval of data, analysis and manipulation of data are done within Arc/ info environment for an effective presentation of both graphic and non-graphic data. The road network file has data linear feature, the length of arcs, travel time, traffic spots and road class. The housing unit file has data on the number of houses and housing type, using the spatial and network modules in Arc/

Info various routing and waste production scenarios are generated and interpreted graphically and non- graphically for results.

Figure 2. Design of the Waste Collection Optimization GIS



Database Development

While a model is a vital part of planning evaluation, the output is the input of carefully structured data with transparent assumptions that helps in the decision support process. The decision-maker should then be able to rely on this technical support producing a wide range of out puts from the model. An effectively integrated data into common reference system allows the comparing of data in different forms ensuring the crucial elements of data interpretation and visualization.

Data Requirement for Residential Waste Collection

A comprehensive waste collection optimization framework should incorporate costs estimates, population estimation, resource allocation, collection strategies and various disposal options. The data needed would include;

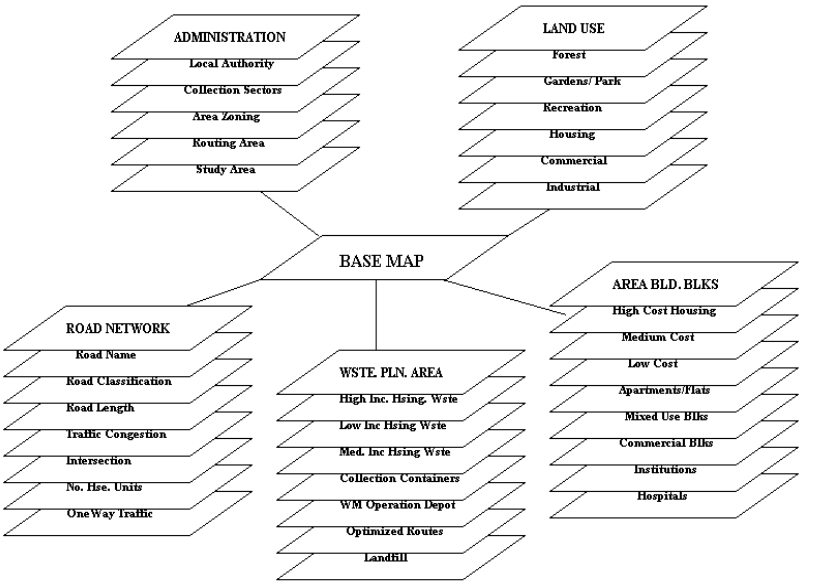
- Costs of management based on transport, equipment, collection and disposal
- Planning zones and boundary restrictions from local, area and waste management plans
- Demographic data on population and economic status based on the type and number of buildings or individual dwellings.
- Socio-economic data linked to infrastructure and land use, housing, hospitals, industries and institutions.
- Waste management facilities on the location of operation depot, storage containers, and transfer stations and landfill site.
- Detail roads and street data based on road network for accessibility, linkage, road classification, travel cost and time estimate.

These data are generally collection from information provided by the waste Management Company (AFSB) and the local council (MPPJ). Other data are available in secondary source such government gazette and local plans and observatory survey is the conducted to verify the data. The detail road and street data is acquired from published directory of the Petaling Jaya and the local area.

The GIS waste collection database involves five major coverages, the base map, administrative, land use, detail road network of the study area up to the waste disposal site and the project area buildings. The attributes to be inputted are as variously described above. The database most essential information on the road and housing that allow the simulation of various waste collection scenarios. The area buildings are digitized based on the entire

street building or housing structure, which may comprise several housing units.

Figure 3. Framework of Database for Waste Collection GIS



A local plan map is used as the base map from which the five layers of coverage are digitized on table and screen on AutoCAD. The layers AutoCAD format "dwg" are then converted into "dxf" format and transported to Arc/ Info for detail editing, the topology function is used to build and clean the layers removing dangling nodes and ensuring perfect intersections of the line features and close of all polygon features. The Arcedit module in Arc/ info allows for intensive editing and through cleaning particularly when dealing with road networks which requires nodes and intersection to be to the point. The layers are again individually converted into "shape" ArcView format for data inputting. Both Arc/ Info and ArcView are used for inputting attribute

data, ArcView particularly proves very useful when dealing with the extensive road network data. A road or line in graphics present tens of arc segments in the attribute table, using the calculate function in arc view arcs requiring the same name and attributes are easily inputted. Using this method the time spent on inputting attribute data on the road network of the study area, 3753 arcs was reduced by some couple of days.

Administrative and Land use

The first two coverages of the waste collection GIS display graphic and non-graphic data on administrative boundaries and on land use. The administrative has attributes of boundaries of local, municipal, study area and waste collection planning sectors allowing for the determination of boundary limit for the waste collection optimization study. The land use on the other hand displays attribute of general land use zoning, housing, industrial, institutional, open spaces/ forest, parks and recreation area. Development restrictions can be assessed and determined based on these attributes.

Housing File

The housing coverage presents attributes on building function by street for graphic and non-graphic analysis and presentation. Buildings are initially identified as commercial, institutional, hospital and housing and housing, the number of individual houses on each street building block. The number of housing units is used to estimate the number of residence based on the assumption the Petaling Jaya municipal household size of 4.6 and the national average household size of 5. The population is therefore:

P = h 5

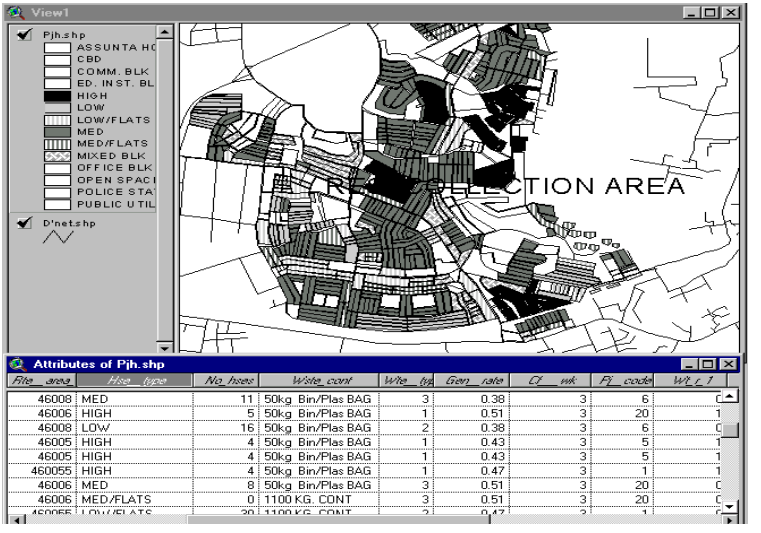
Where P is number of residence; h = no. Of housing units; 5 is the national average household size.

The houses are further identified by socio-economic characteristics into High, Medium and Low cost houses; different income levels influence waste generation and waste composition

Residential Waste Generation in Petaling Jaya
Low Income - 0.62 kg / p / cd.
Medium Income - 0.44 kg / p / cd.
High Income - 0.68 kg / p / cd.

The expected waste on offer for collection is generated based on this per capita waste generation at different income levels and the population or household size. Categorizing waste at this level is significant in determining the suitable disposal methods and also identifying target area for effective assessment and implementation of recycling and composting policies and plans.

Figure 4. Residential Building Blocks on ArcView



A presentation of residential and area build blocks based on the function and socio economic status of building. A total of 477 blocks are residential, a street may comprise 10 to 15 terrace houses on one side of the street. Where housing and commerce are combined they classified separately as mixed block because the type and quantity of waste to be collection will be influenced by the multiple function of the block. Overall 57% of the residential building blocks represent medium income housing. Waste stream and type can be determined and proper collection and disposal options. Using the waste generation for different income housing, waste production is calculated and predicted to determine the quantity, density and composition,

$W = 5h \times g$

Where W is quantity of waste

h is the number of housing units

5 is national household size

g is the per capita waste generation for housing type of the routing area

This attribute data helps to identify whether the waste suitable for recycling, composting or landfill base on the assumption, survey and calculation showing that on the average over 70% of house hold waste from high income residence is recyclable, while that from low income is compostable. Flats and apartments where common containers are located for pickup and terraces requiring house-to-house waste collection again classify housing.

Road Network File

This file presents various network characteristic data, road and street length for the calculation route distances and travel time and also the number of pickup and quantity of waste on each residential street. The travel time is calculated based on the speed of collection trucks from operation depot to collection and from collection area to disposal site.

$$T = 60 / S \times D$$

Where T is calculated travel time

S = the speed of collection truck

D = distance to be traveled

60 = minutes in an hour

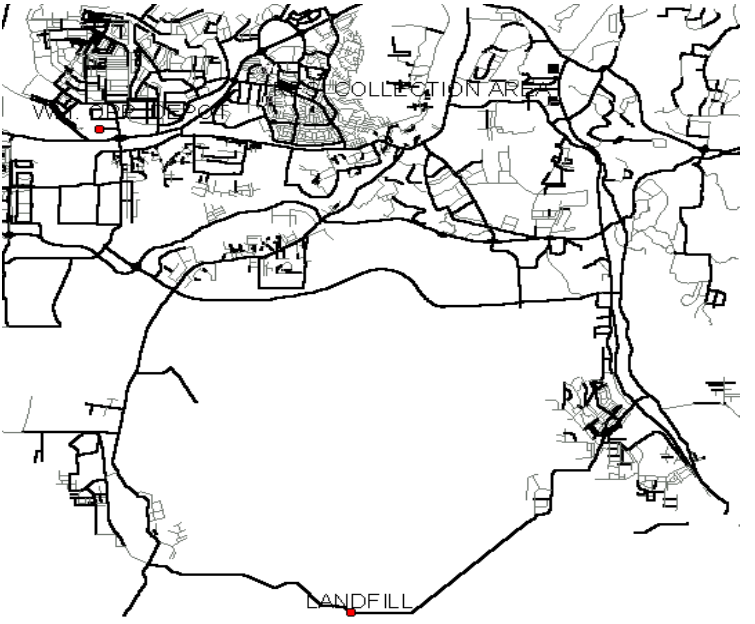
Roads are also classified based on the national road classification of high ways, primary, district, local distributors and minor roads. This attribute is an easy determinant of road characteristics in terms of road width, size and capacity. High ways requiring the paying of poll are identified separately because using these roads though shorten the time travel increase the cost of transportation.

Primary, district and local distributor roads provide high vehicle capacity and allow rapid travel are classified as mass transit roads, the travel time on these roads are low because a waste collection truck may travel at the speed of between 30 to 50km/h form collection sectors to waste disposal site. Road intersections and junctions with incidence of traffic at certain time periods are identified and excluded from the mass transit roads.

A schematic presentation the models network showing roads from the waste management operation depot to the residential collection areas and to the disposal site some kilometers away. Road classified as mass transit having higher vehicle capacity and allowing faster travel are presented in dark bold lines and the residential area showing compact road network light lines.

A route code attribute based on the postal code of each collection area is used to facilitate the identification of each collection routing sector separate from others. The travel time of a waste truck passing through these residential roads at a speed of 5~7km/h is calculate with time spent on house to house pick up 30 seconds and container at flats and apartment 1 minute 30 seconds.

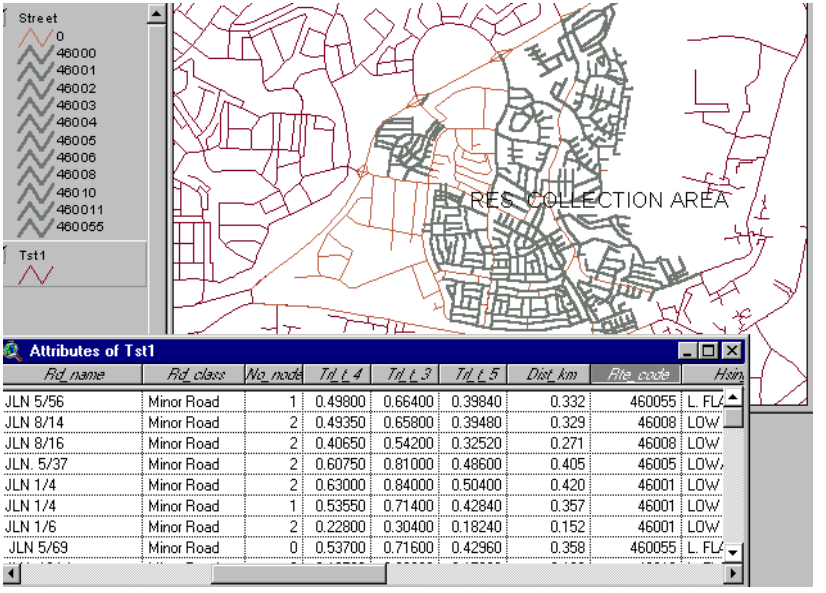
Figure 5. A Model Network



Notes: Bold lines: Distributor roads classified as Mass Transit
Thin Lines: Residential and local area roads
Dot/ Spots: Location of Landfill and waste management operation depot

The assignment problem based on the traveling salesman algorithm is solved to optimize the route system for the residential collection. The assignment problem presents a state of a given network where Xij is a variable such that Xij = 1, if node i is assigned to j and Xij = 0 and the coefficients Cij is the cost of assigning node i to j. The assignment problem is to find 0 – 1 variable Xij so as to minimize:

Figure 6. Detail Residential Road shown by Collection Sectors



$$[1] \quad \text{Min: } z = \sum_{j=1}^{n} \sum_{i=1}^{n} C_{ij} X_{ij} \qquad \text{.....Eq 1}$$

Subject to

$$[2] \quad \sum_{i=1}^{n} X_{ij} = \sum_{j=1}^{n} x_{ij} = 1 \ (\text{for all } i \text{ and } j = 1, 2, ., n) \qquad \text{.....Eq 2}$$

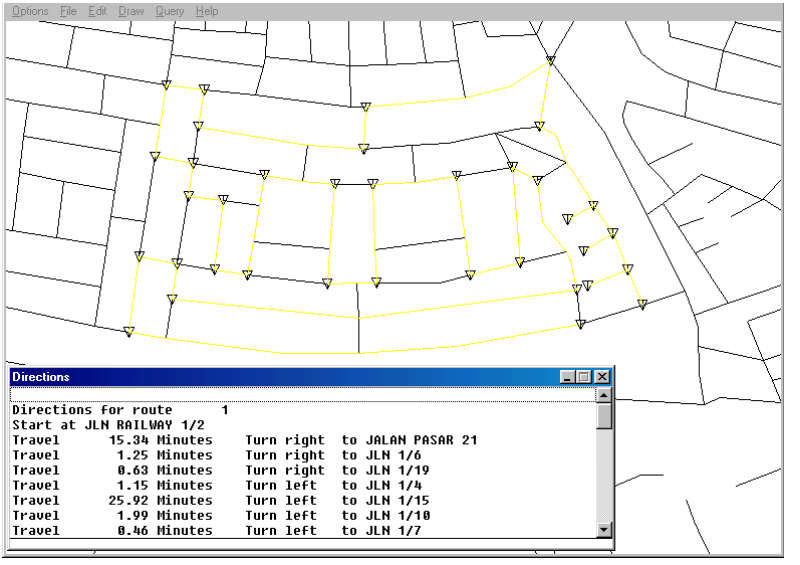
and

$$[3] \quad X_{ij} = 0 \text{ or } 1 \qquad \text{.....Eq 3}$$

In solving the traveling Salesman problem a similar scheme is used, where Xij = 1 would mean that truck travels directly from node i to j and Xij = 0 would indicate that it does not. And assuming assignment cost Cii = 8. The Cij

is the shortest distance from node i to j, to generate an optimized route network following through all node/ intersections, a cost matrix is worked out for the entire residential roads to determine the sequence of roads to be included in the route according to collection sectors. One collection sector has over 30 intersections with varying road lengths of roads, alphabets and round numbers used as codes for the intersections and length in the network to facilitate easier calculation of the matrix for the optimized route.

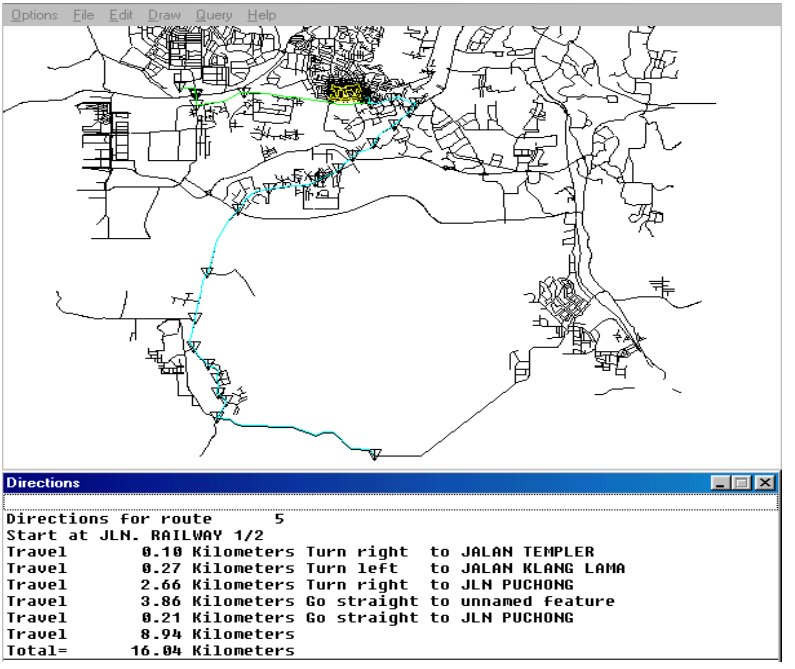
Figure 7. Collection Route Generated on Arc/ Info



Based on the optimized route for residential waste collection, a route direction is generated for drivers that show the travel time at the speed of 7km/h including the pick up time for waste, the total time calculated is 3 hour 41 minutes for this optimized route sector. . The database also allows the estimation of the expected waste to be collection making it possible at what exact point along the route the collection truck is likely to be full. This

information is helpful to management in assessing whether to dispatch one collection truck for three shifts or to send as many trucks based on their capacity to collect the waste at once.

Figure. 8 Disposal route generated on Arc/ Info



Routes are generation from collection areas to disposal site using the tree building method where a route taken on the mass transit roads is explored only if it proves promising with a short path on the way to the location of landfill. Figure 7 displays routes from waste management operation depot to collection section, after collection the route is generated to the disposal site indicating the direction and the distance to be traveled in kilometers. The total

distance to be covered from collection to disposal as determine by the system is 12.7km.

The entire optimized routes are then linked to the GIS network file using linear programming in Arc/ Info. Analysis of the database for the waste collection optimization process is carried out in Arc/ Info NT where a separate node attribute table (NAT) and an arc attribute table (AAT) is created. Using the dynamic segmentation function points and line attributes can be entered in one arc; the network analysis module in Arc/ Info has many functions that allow the exploration of various routing scenarios.

Analysis on the Waste Collection GIS

Different analyses are made on the database, on the base map drawing management, reviewing of the waste collection sector and boundary areas is carried out. Demographic analysis is carried out on residential building block and waste collection planning area coverages. Waste distribution and building type and function reporting is conducted on residential building blocks and waste collection planning area. Traffic situation reporting and vehicle routing is carried out on the road network, collection planning area and residential building. Database and drawing management is carried out in all the coverages as an important aspect of systems development. The waste collection optimization modeling and analysis covers mainly the network, residential building and waste generation. Table 1 summarizes the various required analysis for the waste optimization GIS.

Discussions And Conclusion

It is evident that GIS can considerably enhance the process of efficient waste collection where modeling, analysis and mapping are concern. However a major deterrent for local council and private agencies dealing with waste management in utilizing the capabilities provided by this technology is the large amount of time and effort needed to set up the required GIS database. This includes the collection of the required data to input in the

model and obtaining the relevant coverage for the analysis and generating results. Data on housing based on socio-economic status is rear and may require a survey; the size, location, structure and the number of rooms may however be determining factors.

Table. 1 Required Analysis for Waste Collection GIS

ANALYSIS	B. Map	Bdy. Area	L. Use	R Bld Blk	R Netwk	WC P.Area
Demo. Analysis				X		X
WC. St. Reviewing	X	X		X	X	X
Wste Prod Analysis		X				
WD. Reporting		X		X		X
Invent. Loc. WM. Facilities		X		X		
B.T/ F Reporting		X		X		X
R/ St Char Coding					X	
Traffic Reporting				X	X	
Vehicle Routing				X	X	X
D. B/ Drawing Manag.	X	X	X	X	X	X
WC Opt Modeling		X		X	X	X

Notes: WC St Reving: Waste Collection Reviewing, WP: Waste Production, WD: Waste Distribution, Invent Loc WM: Inventory of location of Waste Management Facilities, BT/ F Repting: Building Type and Function Reporting, R/ St Char Cding: Road/ Street characteristics Coding.

Detail data for road network analysis proves difficult to acquire; the available network files in digital format are very expensive and not fully developed. The network files are mainly road and street central lines and the data that come that comes with it are some times grossly inaccurate, thus requiring thorough editing and cleaning. A detail residential road is digitized using the using the central line file as base cover and the two files are merged together, in this process having other GIS software as backups may prove handy. Some difficulties may arise when merging the two files with Arc/ Info due to data structure and in using Map/ Info there is the possibility of line

duplications, the two networks are superimpose on each other and having separate attribute tables thus corrupting the entire attribute table.

Generally the difficulty of developing a database for network analysis and waste collection cannot be under stated however, the reward for the effort once sufficient data are held in the GIS, is the various network and waste collection scenarios that may be modeled to cover a variety of differing circumstances. The contribution made by GIS in development of the database for this waste collection optimization process is immeasurable. Dealing with road network requires vast data inputs, GIS proves to be an invaluable data tool for managing and visualizing the data, calculations could readily be made on the data at the time. The planning process is legitimately presented as a comprehensive assessment not restricted to particular aspects but seeking to provide a way of developing an integrated approach.

A properly structured database in a GIS provide is a powerful integrated system that brings the capability of looking at the real world in the form of maps and physical locations in the realm as a modeled world generated by design systems and road network models. Over 60km of road network is considered in this database representing a data set of about 2.3 mega bytes stored in a PC – based system, the GIS presented the ability to transform this data greatly and helping in the presentation and the interpretation.

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