SOLID WASTE MANAGEMENT FOR ENVIRONMENTAL PROTECTION. A CASE STUDY OF ACCRA (GHANA)

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ABSTRACT

For many years now, the general sanitation of Accra has posed many challenges to the Accra Metropolitan Authourity (AMA). With the growing population of Accra now standing at about 20% of the population of Ghana, one of the most demanding aspects of the problem of the growth of Accra has been with its solid waste management. What has brought this particular problem into sharp focus is the need to develop a tourism industry in Ghana. One way to meet this challenge is to map out a cost effective privatisation policy for the daily collection and disposal of all the solid waste.

Projected economic trends in Ghana indicate that tourism as an industry has a good potential, and since poor sanitation can impede the growth of tourism, it is mandatory that no effort be spared to meet the challenge posed by the solid waste disposal problem in Accra. Further to this, such a policy has been proposed, the heart of which is a mathematical model of the Accra solid waste collection and disposal system. The model was developed and solved as a transportation optimization problem.

To further exploit the economic potential of the huge amounts of solid waste generated in and around Accra (which presently stands in the order of 800 tonnes a day), it is proposed that the waste be recycled. A mathematical model of the recycling process is presented as a linear programming problem. A discussion to the solution of the model has been presented.

Keywords: *Transportation, Optimization, mathematical model, recycling, reconversion, management*

INTRODUCTION

As at 1980, the population of Accra stood at 1.5 million. This population was made up of two major groups. The first group was made up of the normal residents of the city which numbered 1.2 million and the second group which numbered 0.3 million. The second group is normally called "the floating population". The second group were those who came to do their normal daily business in Accra and went back. The population of Accra is reported to be 3.0 million by now. This means about 20% of the population of Ghana now lives in Accra. It is a fact that the AMA faces many grave issues with the issues of sanitation being one of the most important on the agenda. It is therefore quite imperative that the solid waste generated must daily be disposed of with a quick and effective dispatch.

Two major utility institutions in Ghana are The Electricity Corporation of Ghana (ECG) and the Ghana Water and Sewerage Corporation (GWSC). These utilities are fully privatised. Because of their business-like approach to their work, the residents are obviously very alive to their responsibilities by way of paying their monthly bills. Both utilities have the legal backing to demand full monthly payment for their services from their regular customers. The AMA also needs this privatisation philosophy backed by the Ghana government. Since the AMA has no means of generating a just and fair income from its services, solid waste has now become a permanent problem and a source of perennial potential hazard for the residents of Accra.

THE CURRENT SITUATION AND HOW IT IS HANDLED

The responsibility of handling solid waste collection and disposal in Accra is that of The Chief Engineer of the Waste Department of AMA. Since he reports to the appropriate authorities above him, he has no choice but to work with the resources at his command.

It is on record that even though Accra generates at least 800 tonnes of refuse daily, there is only one disposal point where the refuse can be turned to compost. Even though the compost is readily available, it is hard to market it. Because of this, the AMA finds it best to use 75% of the refuse for landfilling in other parts of the city. To make matters worse, facilities are not even available to handle the remaining 25% of the refuse, and it is not clear if the landfilling can go on at the current pace forever. Though the Ghana government has one time or the other helped the AMA to secure loans to handle the problem, any cursory

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observer can see that the Chief Engineer has no way to face the challenges posed by the solid waste disposal problem in Accra.

There are only 200 refuse containers to serve a population of 3.0 million. This means that on the average, 15,000 residents have access to only one refuse container. There are only 22 bin type waste disposal vehicles which means only one vehicle can service as many as close to 150,000 residents. There are three incinerators but none of them is working as of now. With all these handicaps it is not difficult to see why solid waste matter has been very difficult to get rid off in Accra.

PROPOSED MANAGERIAL STRATEGY BY AMA

To enable the Waste Department handle the waste disposal problem in Accra, the whole system must be put on a sound business footing like the ECG and GWSC. Instead of offering solid waste disposal as a social service, the AMA needs the political and legal backing to achieve a privatisation policy. However, the aim must not be that of taxing the residents for the collection and disposal of their waste for them only but to derive the maximum benefit from the waste by way of sorting the refuse, marketing what can be marketed and recycle what can be recycled all for profit.

The marketing policy must be backed by law of parliament. There is an existing law which demands that any new building must have potable water supplied by GWSC. Similar laws must be promulgated for AMA.

If the AMA gets the legal backing by government just like ECG and GWSC, the means to generate a fair and just income from their services will be there. However, unlike the ECG and GWSC which charge just for their services, AMA will in addition have a few commodities to sell after offering their service. With the necessary resources at his command, the Chief Engineer of the Waste Department can then have both the mandate from the government and the economic resources to rid Accra of the menace of solid waste.

SOLID WASTE MANAGEMENT

The term solid waste management is used to describe the collection and disposal of solid waste materials. Implied in the term is that such activities must be optimised with respect to economics, public health and the environment. Both the collection and disposal activities are influenced by the quantity of solid waste generated. For Metropolitan waste as being considered, factors such as population density, socio-economic status of the population, climate and the frequency of collection service are some of the important factors to be considered. Consequently, as part of the privatization policy, it is imperative to carry out surveys in order to determine accurately all the relevant factors and figures. A mathematical model can then be used to forecast quantities of solid waste generated within a particular sub-district.

SURVEY PARAMETERS AND THE MATHEMATICAL MODEL

Assuming AMA has managed to get the Ghana government to incorporate it into a private institution backed by the necessary by-laws just like the ECG and GWSC, the first assignment they have to tackle is to collect accurate and reliable field data in order to determine the economic and competitive forecast of fair and just income for their services. These parameters are all as defined in the nomenclature and they will be used in all the equations as stated below. Basically, the survey will collect data such as the various types and number of houses and institutions in the respective areas within the sub-district, the types and the nature of refuse generated by each type of house or institution, the frequency with which the refuse can be collected, the various distances from collection points to disposal points and the like [1].

Solid waste is always generated from four sources apart from the hospital wards. (Any form of refuse from a clinic or hospital wards must be incinerated because of its pathological nature). Beter still such refuse can be turned to biogas and used as fuel. The four other sources are; residential, commercial, industrial and institutional. The different types of wastes generated from these sources are given by:-

$$x_r = h_s n_s + h_m n_m \quad (1)$$

$$x_c = h_c n_c \quad (2)$$

$$x_{in} = h_{in} n_{in} \quad (3)$$

$$x_{ins} = h_{ins} n_{ins} \quad (4)$$

From the above four equations the total quantity of refuse collected within a sub-district will be given by:-

$$x_T = x_r + x_c + x_{in} + x_{ins} \quad (5)$$

It is because of the many factors of dependent variables in equations (1) to (5) that surveys must be carried out at regular intervals to enable easy forecasting. For the purposes of this work, it was decided to double the current value of waste generated. The idea was to tie the value of waste generation to the population growth rate and this means the value used in this work can take care of at least between 5 to 10 years. Strictly speaking, correct values must be forecast by surveys. If regular surveys are carried out, then it should be possible to employ regression analysis to predict values of waste generation. However, it is on record that the Waste Department carried out a survey of refuse composition as far back as 1976. Four types of surveys were done. A house to house collection survey was done in a predominantly high income but residential area called "East Cantonment", another one at a predominantly commercial area called "Kaneshie Market", another at a predominantly low income area called "New Town" and the last one for the average of the whole of Accra [2]. (See Table1 below).

TABLE 1: SURVEY OF REFUSE COMPOSITION OF VARIOUS PARTS OF ACCRA

	Survey no.1 %	Survey no.2 %	Survey no.3 %	Survey no.4 %
1. Organics	69.0	96.4	90.0	87.1
2. Paper	15.5	2.1	3.0	5.7
3. Metal	7.0	0.01	2.2	2.6
4. Textile	1.9	0.51	1.1	1.2
5. Glass	1.5	0.01	0.7	0.7
6. Plastics	3.7	0.04	0.5	1.3
7. Others	1.4	0.93	1.6	1.4
Totals	100.0	100.0	100.0	100.0

Legend:-
Survey no.1; House to house collection at "East Cantonments"
Survey no.2; "New Town" Market refuse
Survey no.3; "Kaneshie" public dumping
Survey no.4; Accra total

THE MATHEMATICAL MODEL

Because as much as 80% of the expenditure for solid waste management may be used to support collection activity [3], any significant reduction in the cost of solid waste management must be gained primarily by improving the efficiency of collection.

Further to this, the solid waste collection problem has been modelled into a transportation problem. Stated officially it may be asked:- "How many 8 ton trucks do we need to dispatch every bit of refuse generated everyday in Accra from their respective collection points to the disposal points at a minimum cost?".

Stated mathematically, it would be desired to minimize the cost of transporting all the solid waste to their disposal points. The objective function is given by:-

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij}\, c_{ij} \qquad (6)$$

subject to:

$$x_{ij} \geq 0 \quad \text{for all } i, j \qquad (7)$$

and

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \qquad (8)$$

The cost of transporting the waste from a collection point i to a disposal point j is a function of the distance between the two points.

$$c_{ij} = f(d_{ij}) \qquad (9)$$

Rich [3] gives a formula for calculating the unit cost of transporting solid waste based on an emperical relationship given by:-

$$C_{ij} = \frac{[2.55+(0.325S)+(5.40M)+0.95]}{(60S)}\, t_{ij}\ \$\ \text{ton}^{-1} \qquad (10)$$

In the equation just above, M stands for the number of men working on the truck and this is taken as 2. Similarly, S stands for the size of the truck which is taken as 8 tons.

$$C_{ij} = \frac{[2.55+(0.325*8)+(5.40*2)+0.95]}{(60*8)} t_{ij}$$

$$= 0.035208 t_{ij}\ [\$\ \text{ton}^{-1}]$$

The equation just above, is given in imperial units. It was changed to S.I. units. This was done by taking 2.2 lbs as equivalent to 1 kg. to obtain equation (11).

$$C_{ij} = 34.89 \times 10\text{-}6 t_{ij}\ [\$\ \text{kg}^{-1}] \qquad (11)$$

It was considered that the speed of the truck from a collection point to a disposal point may be slightly lower than the speed from a disposal point to the next collection point. This is because from a collection point to a disposal point, the vehicle will be loaded. However an average speed of $\overline{v}$ was taken. Since the distance between two points is d_{ij}, the time t_{ij} is given by:-

$$t_{ij} = \frac{d_{ij}}{\overline{v}} \qquad (12)$$

Substituting for the value of t_{ij} as given above,

$$C_{i,j} = \frac{34.89 d_{i,j} \times 10^{-6}}{\bar{v}} [\$kg^{-1}] \quad (13)$$

Equation (13) above implies that the distances between the various collection points to the disposal systems must be known and in fact they were all determined from the map of Accra. This was done by following the most probable but reasonable route to be taken by the drivers between each pair of collection and disposal points. With the experience of the geography of Accra in view, the routes were determined empathically. By using the scales provided on the maps the distances were determined. Each district consists of the many matrices on the map each of which measures 0.8km by 0.8km. Four of such distance tables were compiled - one for each district. (See Table 2). Equation (13) was then used to compute the unit cost tables.

CALCULATION OF a_i AND b_j

As already stated, only a thorough survey carried out by AMA will enable the accurate forecast of wastes generated within every sub-district. Since this has not been done yet, an attempt was made to assume a reasonably projected breakdown of wastes. However, those assumptions were based on the data of Table 1. From Table 1., the percentages of the organics were taken to represent the amount of waste generated by residential and commercial activities. Therefore the amount of waste generated by those two activities was assumed to be 80% being the order of the average of Survey no.1 and Survey no.4. The other wastes were taken to represent the amount of waste generated from industrial and institutional activities. It was also reasoned that since a lot of commercial activities go on in Accra daily the waste generated by commercial activities was given more weight than the waste generated from residential activities. Similar reasons were given for the percentages attributed to industrial and institutional wastes. See Table 2 and Table 3 below.

TABLE 2: BREAKDOWN OF DIFFERENT TYPES OF WASTE

TYPE OF WASTE	AMOUNT GENERATED AS PERCENT
Residential Waste	34%
Commercial Waste	46%
Industrial Waste	15%
Institutional Waste	5%
Total	100%

The total projected waste was taken as 1,628 tonnes which is double the current figure in order to take care of twice the population of Accra. Based on this assumption the total wastes from each type of community will be as shown below.

TABLE 3: BREAKDOWN OF DIFFERENT AMOUNTS OF WASTE GENERATED DAILY

TYPE OF WASTE	AMOUNT GENERATED IN TONNES
Residential Waste	554
Commercial Waste	749
Industrial Waste	224
Institutional Waste	81
Total	1628

It was the above figures which were used to calculate the wastes generated at each collection point i as indicated in Table 4. shown below.

Though Accra was sub-divided into 4 districts as shown on the map of Accra only the Lower East District was analysed as an example. The values of a_i are as indicated on each last column of Table 4. They indicate the maximum waste that can be collected at a collection point. The collection point locations show a combination of alphanumerics, e.g. collection point location F8 01 means the collection point is located in the matrix formed by the intersection of the letter F at the left and right edges of the map and the number 8 on top and bottom of the map. The location point itself is number 1. This was the numbering system used for all the 44 location points in the Lower East district and for all the other districts. On the first line for example, it can be seen that the distance between Collection Location Point F8 01 and Disposal Point No. 1 is 2.25 km and the distance between the same collection point and Disposal Point No. 2 is 6.30 km. and so on. However the waste generated at Collection Location Point at F8 01 was estimated to be 4072 kg. All the values indicated under last row of Table 5 are the values of b_j which were obtained by sizing the disposal units according to the type of activity (i.e. whether domestic, commercial, industrial or institutional). However, a thorough survey will still be necessary to obtain the accurate mix.

DISPOSAL SYSTEMS

So far there is only one disposal system for AMA. For the proposed privatisation policy, 16 of such disposal systems are required. (See maps in Appendix). The sixteen disposal systems will be able to handle the ultimate load of 1,628 tonnes of solid waste generated

TABLE 4: COLLECTION POINTS TO DISPOSAL POINTS DISTANCE MATRIX (KM) FOR LOWER EAST DISTRICT INDICATING LOAD GENERATED

Collection Location Point	Disposal Point No. 1	Disposal Point No. 2	Disposal Point No. 3	Disposal Point No.4	Waste Generated At Collection Point (Kg)
F8 01	2.25	6.30	8.00	5.00	4072.0
E8 02	0.50	6.25	8.25	4.50	15270.0
D8 03	2.25	4.50	7.50	4.50	15270.0
C8 04	3.50	3.75	9.00	4.50	15270.0
B8 05	4.75	3.50	9.00	9.25	2038.0
F9 06	1.25	7.25	11.50	3.50	4072.0
E9 07	1.50	5.75	9.50	4.50	15270.0
D9 08	2.00	3.75	9.50	5.00	15270.0
C9 09	3.25	3.00	8.00	4.75	15270.0
B9 10	4.75	2.50	7.50	4.25	2036.0
F10 11	2.25	4.75	6.50	2.75	4072.0
E10 12	2.72	4.25	6.50	3.00	4072.0
D10 13	4.75	3.75	8.00	4.75	15270.0
C10 14	5.75	2.50	8.00	4.00	15270.0
B10 15	5.75	2.50	7.75	4.50	2036.0
F11 16	3.50	5.50	6.00	1.00	4072.0
E11 17	4.25	3.75	4.75	1.50	4072.0
D11 18	3.75	2.75	7.00	2.75	15270.0
C11 19	5.25	1.75	6.75	3.50	2036.0
B11 20	6.75	1.25	6.75	4.75	4072.0
F12 21	5.25	4.50	4.50	0.50	4072.0
E12 22	5.75	4.25	3.50	1.25	4072.0
D12 23	5.75	3.50	3.50	2.50	4072.0
C12 24	4.75	1.50	6.00	3.75	4072.0
B12 25	5.75	0.50	5.50	4.50	2036.0
F13 26	5.50	5.50	3.50	2.00	4072.0
E13 27	5.50	4.25	3.25	2.00	4072.0
D13 28	5.50	3.50	2.75	3.00	4072.0
C13 29	5.50	2.50	3.00	4.25	4072.0
B13 30	7.25	1.50	5.75	4.50	2036.0
F14 31	6.75	7.00	2.50	3.00	4072.0
E14 32	7.00	4.75	2.00	3.25	4072.0
D14 33	7.50	3.50	1.50	3.75	26468.0
C14 34	7.50	2.75	2.00	4.50	26468.0
B14 35	7.50	2.75	3.00	5.50	2036.0
F15 36	8.25	8.50	2.50	4.50	26468.0
E15 37	9.25	4.50	1.50	4.75	4072.0
D15 38	8.50	5.00	0.50	5.00	4072.0
C15 39	9.00	4.00	1.50	6.00	4072.0
B15 40	9.00	3.25	2.50	6.50	2036.0
F16 41	9.25	9.50	3.50	5.50	2036.0
D16 42	9.50	6.00	0.50	6.00	15270.0
C16 43	11.50	6.00	2.25	7.00	4072.0
B16 44	11.50	7.00	3.25	8.00	13234.0

TABLE 5: THE OPTIMAL SHIPMENT STRATEGY FOR LOWER EAST DISTRICT:

COLLECTION POINT LOCATION	DISPOSAL POINT NO.1	DISPOSAL POINT NO.2	DISPOSAL POINT NO.3	DISPOSAL POINT NO.4
F801	4072	0	0	0
E802	15270	0	0	0
D803	15270	0	0	0
C804	15270	0	0	0
B805	0	2038	0	0
F906	4072	0	0	0
E907	6704	8566	0	0
D908	15270	0	0	0
C909	0	14398	872	0
B0910	0	2036	0	0
F1011	0	0	4072	0
E1012	4072	0	0	0
D1013	0	15270	0	0
C1014	0	15270	0	0
B1015	0	2036	0	0
F1116	0	0	0	4072
E1117	0	0	4072	0
D1118	0	15270	0	0
C1119	0	15270	0	0
B1120	0	2036	0	0
F1221	0	0	4072	0
E1222	0	0	0	4072
D1223	0	0	0	4072
C1224	0	0	4072	0
B1225	0	0	2036	0
F1326	0	0	0	4072
E1327	0	0	0	4072
D1328	0	0	4072	0
C1329	0	4072	0	0
B1330	0	0	2036	0
F1431	0	0	4072	0
E1432	0	0	4072	0
D1433	0	0	26468	0
C1434	0	0	26468	0
B1435	0	2036	0	0
F1536	0	0	0	26468
E1537	0	0	4072	0
D1538	0	0	4072	0
C1539	0	0	4072	0
B1540	0	0	2036	0
F1641	0	0	900	3172
D1642	0	0	15270	0
C1643	0	4072	0	0
B1644	0	13234	0	0
TOTALS	80000	115604	116806	50000

THE MINIMUM COST OF SHIPMENT = $705.92/day daily which is the projected figure envisaged for the design period.

COLLECTION SYSTEMS

Because the number of standard vehicles required to service the whole of Accra is grossly inadequate, most of them are used to service the predominantly residential but high income areas to collect waste on house to house basis. This step is the most logical step since AMA has to make some kind of income for themselves. Another small number of vehicles is also used to collect refuse from the 200 bins located at vantage points in various neighbourhoods of Accra.

A bin may be either $7m^3$, $10m^3$ or $16m^3$. Because most of the times the waste generated is not carted off with a quick dispatch due to the low level of vehicle round trip times, there is always a spill over and more often than not, the waste is left unattended to for days and even sometimes weeks on end. Sometimes vast quantities of waste is left on private lots. The owner of the property is then left to reclaim his property when he is ready to build. As opposed to this, 183 collection points have been proposed. Each collection point is not just an open bin, but a permanent shelter with roofing well ventilated and protected from the vagaries of the weather. The key is that the waste can be converted to cash and hence must be treated as raw material as is done in any business. There should be facilities to load the 8 ton trucks with the waste at each collection point. All these points have been shown located on the drawings. The idea is exactly the same as the sub-stations designed and constructed by the ECG which can be found all over various neighbouhoods in Accra. Who should pay for the cost of constructing the collection points? The public should pay. The economics of the privatization policy should be such that just as the collection points are indicated on the map, the residents within that sub-district (measuring 0.8km by 0.8km) should be made to pay for their refuse collection point. It is reasonable to assume that if the collection points are placed where they are shown, all the refuse will find its way to the collection points. Designated vehicles can then dispatch the refuse to their respective disposal points.

THE TRANSPORTATION ALGORITHM AND ITS APPLICATION

After the transportation problem was modelled, there was the need to find an algorithm to develop a computer program to solve the transportation problem. The algorithm used to develop program TRANSPOT is the one given below which was from a text by Thie [4]. The language used for the computer program was FORTRAN 77. The methodology of the algorithm is as detailed below:

1. Construct an initial solution by defining

$$u_i = \text{Min}\ \{C_{ij}\},\ i = 1, \ldots, m$$

$$v_j = \text{Min}\ \{C_{ij} - U_i\},\ j = 1, \ldots, n$$

2. Associate with $\{u, v_j\}$ a distribution which flows such that

$$K_{ij} = \begin{cases} \infty, & u_i + v_{ij} = C_{ij} \\ 0, & u_i + v_{ij} < C_{ij} \end{cases}$$

3. Check the unmet demand for each column i.e. $b_j - \Sigma x_{ij}$. If this is zero for all columns, then we have a feasible flow and the problem is solved.

4. Otherwise initiate the labelling procedure:

   (a) Label all rows with surplus units, i.e. rows with $\Sigma_j x_{ij} < ai$. Let I denote this set of rows.

   (b) For each $i \in I$ determine all unlabelled columns j for which $x_{ij} < k_j$. Label these columns with the corresponding row number $i \in I$. Let J denote this set of columns.

   (c) For each $j \in J$, determine all unlabelled rows for which $x_{ij} > 0$. Label these rows with the corresponding column number $j \in J$. Let I denote this new set of labelled rows, and return to step b.

5. Continue this labeling process, moving from rows to columns to rows to columns and so on to determine if there is a column with an unmet demand. If there is no labelled unmet demand then go to step 7. If there is an unmet demand in a particular column, then increase the flow into this column by readjusting the flow values x_{ij} and proceed to step 6.

6. Attempt to solve the resulting distribution problem. For a column with an unmet demand, if there are feasible solutions to the distribution problem, then any such solution is a minimal cost shipping schedule for the original transportation problem.

7. Define a new solution $\{u_i', v_j'\}$.

$$\text{Let } d = \underset{\substack{i \in R \\ j \notin c}}{\text{Min}}\ \{C_{ij} - (u_i + u_j)\}$$

and define

$$U_i' = \begin{cases} u_i + d \text{ for } i \in R \\ u_i \quad \text{for } i \notin R \end{cases}$$

and

$$V_i' = \begin{cases} v_j - d \text{ for } j \in C \\ v_j \quad \text{for } j \notin C \end{cases}$$

Return to step 2 with (u_i', v_j') to replace (u_i, v_j)

RESULTS FROM PROGRAM TRANSPORT

Table 5 shows the computer output of the optimal shipment strategy for the lower East District of Accra only. The capacities of the disposal points are all as indicated on the last row of the table. The computer output also indicated that the minimum cost of transporting all the solid waste generated from the collection points to the disposal points in the Lower East District of Accra is $705.92/day. Similar tables with costs were obtained for the other districts, but they are not shown here since they are all similar to Table 5. The summary of results is shown in Table 6.

TABLE 6: SUMMARY OF RESULT

DISTRICT	WASTE GENERATED	NUMBER OF COLLECTION POINTS	NUMBER OF DISPOSAL POINTS	MINIMUM COST	AVERAGE SPEED
	Tonnes/day			$/day	k.p.h
UPPER EAST	314.78	32	5	520.00	50.0
UPPER WEST	478.46	48	4	784.00	50.0
LOWER EAST	362.41	44	4	705.92	58.0
LOWER WEST	472.35	39	3	1086.31	50.0
TOTAL	1628.00	183	16	3097.03	

CONVERSION OF THE SOLID WASTE

Normally, it should have been possible to suggest that the AMA undertakes recycling of the solid waste on an industrial basis. However, it is appreciated that strict recycling on that basis may not be possible as a first option. Hence the term RECYCLING will not be used. Rather the term CONVERSION will be used. The reason is that so far only one item can conveniently be properly recycled in the correct sense of the word; and that item is the bio-degradable matter which is currently being turned into compost. It will be enough for AMA to just sort the remaining waste and market them as a first option while research proceeds to undertake actual recycling of the remaining waste as time goes on.

However, it has been pointed out that the amount of refuse used in composting constitues only 25% of the refuse generated daily. There is the need to go further than this. Immediately the waste gets to the various disposal points, it should be sorted into the following materials in their seperate compartments [5]:-

i. Plain Glass
ii. Coloured Glass
iii. Plain Paper
iv. Coloured Paper
v. Thermomelting Plastic
vi. Thermosetting Plastic
vii. Ferrous metals (iron, steel etc)
viii. Non ferrous metals (brass, bronze, etc)
ix. Copper
x. Aluminium
xi. Bio-degradable material
xii. Tin

All the items listed above can one way or the other be recycled in various parts of the country. The only difference is that the recycling is being done already by other private institutions albeit on a rather small scale in each case. All those engaged in the small scale recycling go to the refuse dumps and spend hours searching through the refuse to pick what they want. The economic implication is that these people are actual competitors to the AMA.

It is interesting to note at this point that between the late fifties and the late sixties, the Water Works (as the GWSC was known in those days) faced exactly the same situation. During those days, potable water was mainly fetched from standpipes even in the urban centres like Accra and Kumasi. It was not common to have the water metered as is being done now. Some Ghanaians and indeed some aliens also, made good business out of the situation. These ones used to fetch potable water from the standpipes in kerosine tins to houses for a fee. The water porters never paid any income by way of royalties to the Water Works. It was during the mid-sixties that there was the awareness of the fact that those people were doing business with water for which they paid nothing to the government. The practice did not entirely cease until the GWSC was incorporated, the public standpipes were dismantled over a period and water meters were installed in homes.

The main argument put forward here is that if the AMA is to save the capital of Ghana from the present embarrasement, then it must at all cost get into the business of actually recycling the refuse. Since there are other residents and institutions doing it already, it means the AMA can do it much better with better management at maximum profit.

It is a fact that there are people in Accra whose main work is to collect old bottles from refuse dumps, wash them and sell them for a profit. It is these kinds of bottles that are used in hospital dispensaries for liquid drugs. These bottles are the ones used by local bee keepers to bottle their honey. There are others who use these bottles for other purposes like beads (where the bottles are first crushed into powder, melted in ovens and recast as beads). On its part, the AMA can employ the teeming young men roaming the streets of Accra to sort the bottles out into plain glass and coloured glass compartments. They can then sell even the broken glass to the Tropical Glass Factory at Aboso in the Western Region of Ghana. This is just an example.

At the Government ministries of Accra, there is a huge source of waste paper of all sorts. A small incinerator was previously installed right at the ministries to burn waste paper. The bulk of the paper is now sold as scrap. This is not to mention the amount of waste paper which is left on all the refuse dumps and the roadside in the city daily. At least, the plain paper can be marketed to Super Paper Products Co. Ltd. in Accra for the manufacture of toilet rolls. It will be a good idea for AMA to also co-ordinate with the ITTU (Integrated Technology Transfer Unit) in the Greater Accra Region to recycle all the coloured paper into egg trays.

Conversion of Plastics

Of all the solid waste generated the most troublesome is plastic. Any cursory observer in Accra is forced to come to the painful conclusion that no one is in charge of the sanitation of Accra, because of the way plastic bags are all over the place. The waste plastic is mainly from hawkers of all kinds of wares and foodstuffs. Many of these hawkers belong to the floating population and there is no way to check their activities. However, once the plastic is collected it can be recycled.

There are two types of plastics:- Thermomelting plastic and Thermosetting plastic and of the two, the more difficult to handle is thermosetting plastic.

If there is therefore anything 'difficult' which the AMA has to do about the solid waste, perhaps it is how to recycle thermosets into other products. It will be a good idea to engage Biochemists to research into this area. It is on record however that there are people in Ghana who make a living by just picking old thermoset plates, clean them thoroughly and sell them for profit. This is clearly an area which can be fully exploited by AMA. Because the remaining thermosets that cannot be picked are difficult to deal with, they are left as environmental nuisance in every part of Accra.

Thermomelts can be recycled easily once they are subjected to mechanical deformation which can be achieved with a screw extruder. The melt that will be obtained can then be used for blowing other products as is done in conventional production of plastic materials.

Conversion of Metals

The ferrous material could just be collected and sold to establishments like the Tema Steel Works and other iron and steel manufacturers and the non ferrous material like brass, bronze and copper could also be sold to small scale ornament manufacturers. It is a fact that small scale ornament manufacturers pick a lot of scrap for their work. There are times when old items like paper weights, shoe horn and the like are found in the waste and these are picked by wayside retailers. All this implies that the reconversion is possible.

Scrap aluminium has a very big market in the whole country for the manufacturing of cooking pots by small scale industrialists who up to now just pick the scrap metal for free from the refuse dumps.

The bio-degradable matter can still be turned into compost and marketed to the various agencies as has already been suggested. It is comforting to note that this particular activity is a strong point of the AMA and they must be encouraged to handle it more efficiently in order to obtain the maximum profit. For example there is definitely a direct link between the beautification programme of the city of Accra and the amount of compost produced by AMA. It should not be too much to promulgate a law enforcing the Parks and Gardens Dept. of Accra to buy a large amount of compost produced by the AMA for taking care of its gardens in the city. It should not also be too much to demand by law that all establishments and houses whose offices are at a fixed distance (say 20 metres) from the major roads of Accra must beautify their surroundings with the compost produced by AMA. The idea is not only to help in the marketing of this important commodity produced by the AMA, but also the long term effect is to enhance the chance of making tourism a reality in Ghana.

The supply of scrap metal is very huge indeed. It normally comes from tins of evaporated Milk, Ovaltine, Milo, Coffee, Tomato Puree and the rest. The best way to handle this is to obtain a good payload of this important resource and sell it to the small scale industrialists who manufacture bread tins and other containers for confectionery.

THE MATHEMATICAL MODEL OF THE PROPOSED RECYCLING

From the arguments that have been raised, it is proposed that since there are other competitors already in the recycling business albeit on a small scale, it should be possible to determine all factors of profit by research. This research work should not be looked on as a kind of a mystery. It should be possible for the appropriate staff in the research team to prepare the appropriate field questionaire which can enable AMA to determine all the relevant factors of the recycling process. For example, it should not take too much to determine the unit profit on each of the separate items. The main idea is to obtain the maximum profit from the recycled waste. Further to this, the objective function of the recycling process will be to maximize the total profit from the solid waste. The mathematical model presented below will consider the marketing model only.

The objective function will therefore be given by:-

$$X.P_o = \Delta_{cg}X_{cg} + \Delta_{pg}X_{pg} + \Delta_{cp}X_{cp} + \Delta_{pp}X_{pp} + \Delta_{tm}X_{tm} + \Delta_{ts}X_t + \Delta_{fm}X_{fm} + \Delta_{nf}X_{nf} + \Delta_{cu}X_{cu} + \Delta_{tn}X_{tn} + \Delta_{al}X_{al} + \Delta_{bd}X_{bd} \quad (14)$$

The following are the constraints:-

Within a specific time, all the solid waste brought to the disposal points must be sorted out into their respective components. This first constraint is therefore related to time. A specific time must therefore be given to T_{cr} i.e. it must be fixed but it cannot be more than 24 hours (according to the official requirement). Stated mathematically:-

$$W_{pg}X_{pg} + W_{cg}X_{cg} + W_{pp}X_{pp} + W_{cp}X_{cp} + W_{tm}X_{tm} + W_{ts}X_{ts} + W_{fm}X_{fm} + W_{nf}X_{nf} + W_{cu}X_{cu} + W_{al}X_{al} + W_{tn}X_{tn} + W_{bd}X_{bd} \leq T_{cr} \quad (15)$$

$$U_{pg}X_{pg} + U_{cg}X_{cg} + U_{pp}X_{pp} + U_{cp}X_{cp} + U_{tm}X_{tm} + U_{ts}X_{ts} + U_{fm}X_{fm} + U_{nf}X_{nf} + U_{cu}X_{cu} + U_{al}X_{al} + U_{tn}X_{tn} + U_{bd}X_{bd} \leq C_{cr} \quad (16)$$

It is customary for management to allocate a fixed budgetary allocation for its projects. On the other hand it is reasonable to expect a certain amount of minimum revenue from the sale of various materials. The constraint on budgetary aiocation is implied by inequality (16) and the constraint on revenue is implied by inequality (17).

$$R_{pg}X_{pg} + R_{cg}X_{cg} + R_{pp}X_{pp} + R_{cp}X_{cp} + R_{tm}X_{tm} + R_{ts}X_{ts} + R_{fm}X_{fm} + R_{nf}X_{nf} + R_{cu}X_{cu} + R_{al}X_{al} + R_{tn}X_{tn} + R_{bd}X_{bd} \geq R_{cr} \quad (17)$$

The following four inequalities all have to do with payload, of the various materials like glass, paper, metal and plastic. Their total weights must attain particular values before they can be transported to the processing or marketing centres; e.g. the sorted glass may have to be transported to Aboso, a town more than 300 km by road and the transportation cost must be offset by a given payload:-

$$X_{pg} + X_{cg} \geq W_{tg} \quad (18)$$

$$X_{pp} + X_{cp} \geq W_{tp} \quad (19)$$

$$X_{ts} + X_{tm} \geq W_{pl} \quad (20)$$

$$X_{fm} + X_{nf} + X_{cu} + X_{al} + X_{tn} \geq W_{mt} \quad (21)$$

The space allocated to each component of solid waste is also fixed, i.e. the volume of space for each component is within a certain value. This constraint has to do with the fact that each material will have a specific space allocated to it at the sorting point.

$$(\rho_{gl})^{-1}(X_{cg} + X_{pg}) \leq V_{cg} \quad (22)$$

$$(\rho_{pp})^{-1}(X_{pg} + X_{cp}) \leq V_{pp} \quad (23)$$

$$(\rho_p)^{-1}(X_{tm}) \leq V_{tm} \quad (24)$$

$$(\rho_{ts})^{-1}X_{ts} \leq V_{ts} \quad (25)$$

$$(\rho_{fm})^{-1}X_{fm} \leq V_{fm} \quad (26)$$

$$(\rho_{nf})^{-1}X_{nf} \leq V_{nf} \quad (27)$$

$$(\rho_{cu})^{-1}X_{cu} \leq V_{cu} \quad (28)$$

$$(\rho_{tn})^{-1}X_{tn} \leq V_{tn} \quad (29)$$

$$(\rho_{al})^{-1}X_{al} \leq V_{al} \quad (30)$$

$$(\rho_{bd})^{-1}X_{bd} \leq V_{bd} \quad (31)$$

SOLUTION TO THE MODEL OF THE PROPOSED WASTE

Recycling/Reconversion

As can be seen from relationshipss (14) to (31), the recycling/reconversion model has its objective function with 17 constraints. Since the number of constraints is less than 100, the simplex method can be employed to solve the model. The premise however is that all the necessary data would be available.

DISCUSSION OF RESULTS, RECOMMENDATION AND CONCLUSION

(i) The sore state of environmental problems caused by the solid waste generated in Accra has been highlighted. Instead of the present practice of landfilling, open refuse incineration and unhygienic refuse dumping in many places in Accra, it has been suggested that the collection of refuse be effected at minimum cost. This is imperative because refuse collection alone accounts for 80% of the cost of solid waste management [3]. Further to this, 183 collection points and 16 disposal points have been strategically placed at various parts of Accra to make this feasible as shown in Figure 1.

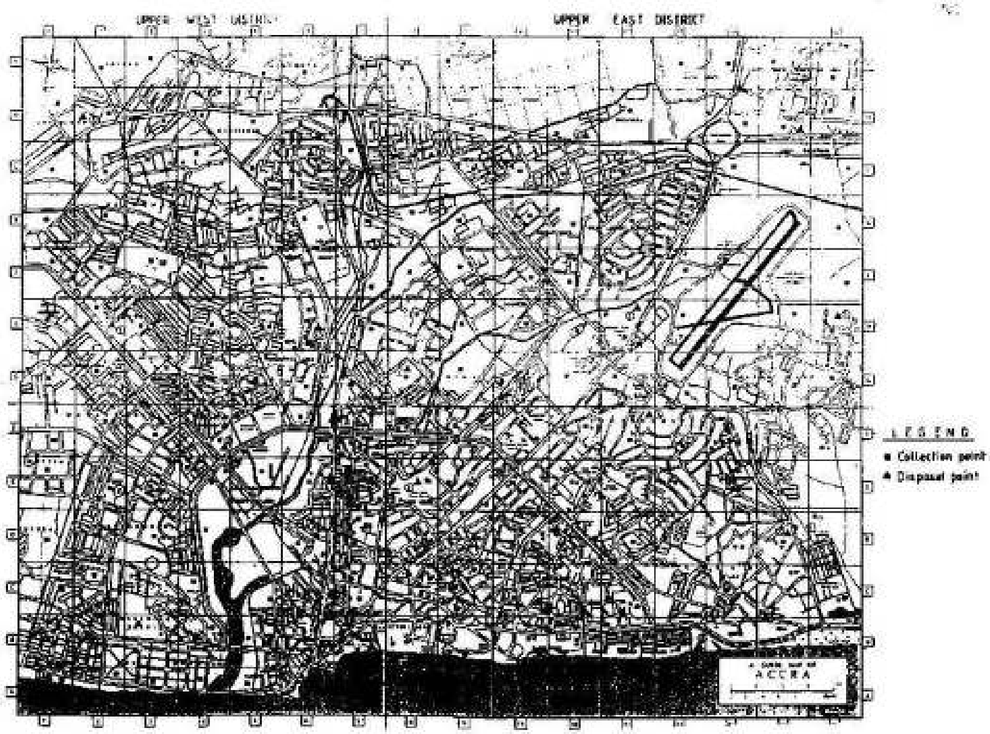

Fig. 1: Upper East District

(ii) Table 5 shows the computer output for the optimal shipment strategy for the Lower East District of Accra which was selected as an example out of the 4 districts. The formula given by Rich in equation (10) was found to be appropriate but it was multiplied by a factor in order to make the costs reflect the current economic trends in the private transportation sector in Ghana.

(iii) Table 6 above shows the summary of results for the 4 districts into which Accra was subdivided. The results indicate that the cost of hauling 1,628 tonnes of refuse from all the collection points to the disposal points is $3100 per day. Since the proposed arrangements are based on twice the amount of refuse generated presently, it means the proposals may be able to take care of solid waste management in Accra at least for the next 5 to 10 years.

(iv) Of the 4 districts, the Lower West district is the most expensive in terms of refuse collection costing about $1100 per day, though the load is a shade less than that of the Upper West. This is due to the fact that the disposal points in the Lower West district have a wider spread; i.e. the linear distances between the disposal points are longer, thus making the round trip costs higher. The Lower West district has both the capital's only Teaching Hospital and the biggest market in Accra. However the Upper West district has the largest load of refuse because it has the highest concentration of local industries in the city. The Lower West district was given only 3 disposal points because of the need of keeping any disposal point well away from the Hospital.

(v) Table 6 also indicates the average speed at which each vehicle can travel in each district. All the vehicles can travel at the stipulated speed limit of 50 k.p.h. during the day with the exception of the vehicle working in the Lower East district which can travel at 58 k.p.h. which is higher than the speed limit. This means the vehicle working in the Lower East district can work either during the late evenings or preferably at night when the vehicular traffic is much lighter. See Figure 2.

(vi) The total cost of haulage has been calculated to be $3100 per day. It is of interest to note that based on a population of 3.0 million for Accra, the cost of refuse collection to each inhabitant is 3 cents a month. Perhaps this can be used as a basis of calculating monthly bills, depending on the type of activity; i.e. whether the activity is domestic, commercial, public or industrial.

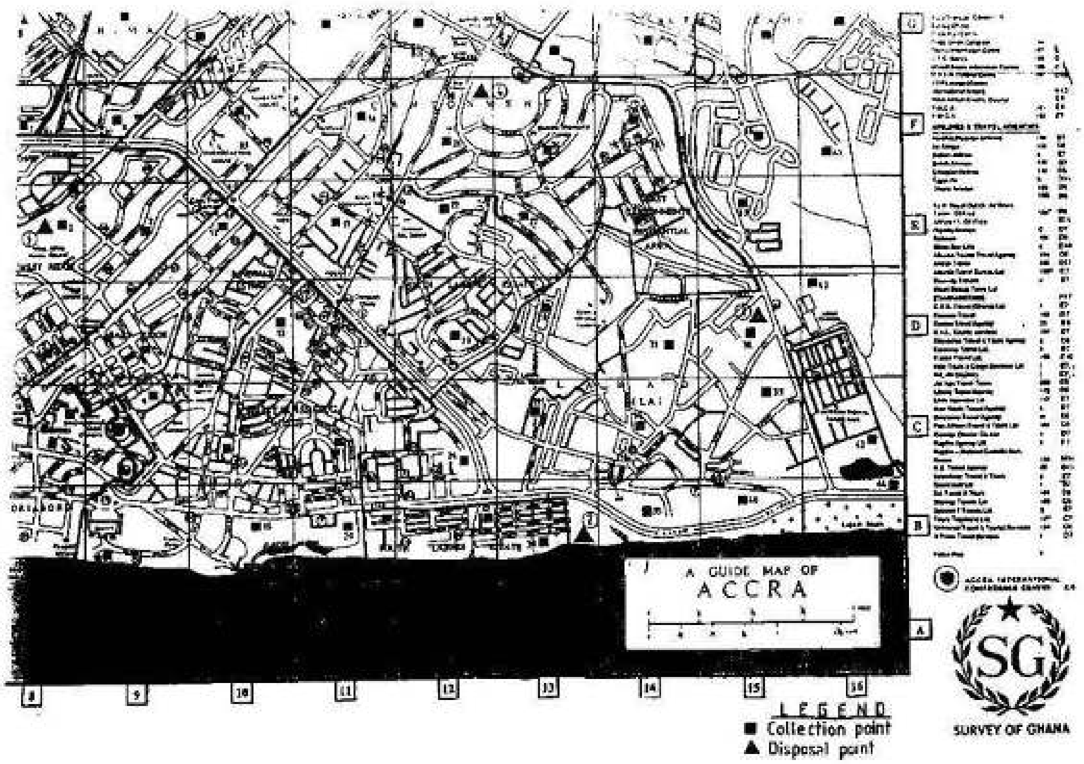

Fig. 2: Lower East District

(vii) Instead of the current practice of waste disposal, it has been suggested to recycle the waste. A mathematical model of the recycling process has been presented, but a practical solution to the recycling process cannot be offered as has been done for the refuse collection because further data has to be collected before a practical solution can be offered.

(viii) It has also been suggested that the bio-degradable material be turned to bio-fertilizer. Another way though is to turn the bio-degradable material to Biogas by employing Anaerobic Sanitation. The Biogas can be used to run electric generators.

In conclusion, environmental issues without doubt have assumed global dimensions. Also, Ghana desires to attract both tourists and investors in order to further her development. Moreover, there is a Secretariat in Accra for PANAFEST which is now a permanent activity in Ghana every 2 years. There is therefore an urgent need to deal with this peculiar problem of refuse disposal in Accra once and for all.

ACKNOWLEDGEMENTS

The author wishes to make particular mention of Prof. Kwesi Andam of Civil Engineering Dept., UST Kumasi and Dr. Ralph Asabre of the Mining Engineering Dept., UST School Of mines, Tarkwa, who read through the paper and made very useful suggestions. The author is much indebted to them.

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NOMENCLATURE

a_i = total quantity of waste transported from collection point i [kg]

b_j = capacity of disposal point j [kg]

c_{ij} = unit transportation cost of hauling waste from collection point i to disposal point j [$kg^{-1}]

c_{ir} = Critical budget allocation [$]

d_{ij} = distance from collection point i to disposal point j [km]

h_{cm} = commercial waste coefficient in a sub-district.

h_{id} = industrial waste coefficient in a sub-district.

h_{it} = institutional waste coefficient in a sub-district.

h_{mf} = household waste coefficient for a multi-family unit.

h_{sf} = household waste coefficient for a single-family unit.

m = number of collection points

n = number of disposal points.

n_{cm} = number of commercial units in a sub-district.

n_{mf} = number of multiple family units in a sub-district.

n_{in} = number of industrial units in a sub-district.

n_{it} = number of institutional units in a sub-district.

n_{sf} = number of single family units in a sub-district.

R_{cr} = critical revenue generated by solid waste. [$]

t_{ij} = time taken for a vehicle to move solid waste through a normal traffic from point i to point j [hr].

x_{cm} = total waste generated by the commercial sector in the sub-district [kg].

x_{ij} = quantity of waste transported from collection point i to disposal point j [kg].

x_{id} = total waste generated by the industrial sector in the sub-district [kg].

x_{is} = total waste generated by the institutional sector in the sub-district [kg].

x_{rs} = total waste generated by the residential sector in the sub-district [kg].

x_{TW} = total solid waste generated in a sub-district [kg].

C_{wk} = critical working period within a working day [hr].

P_o = total profit in the objective function [$].

U_{al} = unit cost of converting aluminium [$kg^{-1}].

U_{bd} = unit cost of converting bio-degradable matter [$kg^{-1}]

U_{cu} = unit cost of converting copper [$kg^{-1}]

U_{cg} = unit cost of converting coloured glass [$kg^{-1}].

U_{cp} = unit cost of converting coloured paper [$kg^{-1}].

U_{fm} = unit cost of converting ferrous metal [$kg^{-1}].

U_{tm} = unit cost of converting thermomelt plastic [$kg^{-1}].

U_{nf} = unit cost of converting non-ferrous metal apart from aluminium [$kg^{-1}].

U_{pg} = unit cost of converting plain glass [$kg^{-1}].

U_{pp} = unit cost of converting plain paper [$kg^{-1}].

U_{ts} = unit cost of converting thermoset plastic [$kg^{-1}].

U_{tn} = unit cost of coverting tin [$kg^{-1}]

The subscripts used above for the unit costs will now be implied throughout the paper for the remaining variables.

Remaining variables are defined below:-

R = revenue generation factors indicated by subscript [$Kg^{-1}].

v = volume of space to a particular material [m^3]

W = work rate factor indicated by subscript [hrkg^{-1}].

X = weight of a particular type of waste indicated by subscript [kg].

β = unit cost coefficient.

ρ = bulk density of a particular type of waste indicated by subscript [kgm^{-3}].

Δ = unit profit of a particular type of waste indicated by subscript [$kg^{-1}].