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OPTIMIZATION OF SOLID WASTE MANAGEMENT SYSTEM USING DESIGN OF EXPERIMENT (DOE) AND RESPONSE SURFACE METHODOLOGY (RSM)

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Abstract

In this study, a comprehensive solid waste generation and collection assessment within the study area was undertaken with the view of formulating an optimization model that will help identify the important variables influencing the overall cost of solid waste management and also determine their optimum values. Some of the important variables use in formulating the model include; the number of solid waste collection trips per month (X_1), number of manpower (persons) per collection vehicle (X_2), fuel consumption per day (for each collection vehicle) (X_3) and weight of solid waste collected per trip (X_4).

To develop the model, statistical design of experiment (DOE) using the central composite design method (CCD) was employed. The number of experimental run based on the CCD method was determined with the aid of a simple mass balance equation. Thirty (30) experimental runs were thereafter generated and optimzed using design expert software.

Results of the optimization model revealed that; the number of solid waste collection trips per month ($X_1 = 42$), number of manpower (persons) per collection vehicle ($X_2 = 2$), fuel consumption per day (for each collection vehicle) ($X_3 = 28.02$ liters) and weight of solid waste collected per trip ($X_4 = 6.38$ tons). The optimal solution of selected variables produced an overall cost of N864, 190. The solution was selected by design expert software with a desirability value of 1.000 that is 100% reliability.

***Keywords*: Solid waste management, Transportation cost function, Numerical optimization, Design of experiment, Central composite design.**

1.0: Introduction

Solid waste is the unwanted or useless solid materials generated from combined residential, industrial and commercial activities in a given area. It may be categorized according to its origin (domestic, industrial, commercial, construction or institutional); according to its contents (organic material, glass, metal, plastic paper e.t.c); or according to hazard potential (toxic, non-toxic, flammable, radioactive, infectious e.t.c) [1].

Solid waste generation increases with population expansion and economic development. Improper management of solid waste poses a risk to human health and the environment. In addition, uncontrolled dumping and improper waste handling causes a variety of problems, including contaminating water, attracting insects and rodents, and increasing flooding due to blocked drainage canals or gullies. It may result in hazards from fires and explosions, increased greenhouse gas (GHG) emissions, which contribute to climate change. Planning and implementation of a comprehensive program for waste collection, transportation, recycling and proper disposal can eliminate these problems [2].

Management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. A number of processes are involved in effectively managing waste for a municipality. These include monitoring, collection, transport, processing, recycling and disposal [3]. The basic concept behind waste management is the waste hierarchy, where the most effective approaches to managing waste are at the top.

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Waste management is in contrast to waste minimization. Waste management focuses on processing waste after it is created, concentrating on re-use, recycling, and waste-to-energy conversion rather than eliminating the creation of waste in the initial phases of production [4]. Waste minimization is a process that involves reducing the amount of waste produced in society and helps eliminate the generation of harmful and persistent wastes, thus supporting the efforts to promote a more sustainable society [5]. Waste minimization involves redesigning products or changing societal patterns concerning consumption and production to prevent the creation of waste [4]. Waste minimization usually requires knowledge of the production process, cradle-to-grave analysis (the tracking of materials from their extraction to their return to earth) and detailed knowledge of the composition of the waste.

The most environmentally resourceful, economically efficient, and cost effective way to manage waste is to know how to address the problem in the first place. Waste minimization should be seen as a primary focus for most waste management strategies. Proper waste management can require a significant amount of time and resources. Therefore, it is important to understand the benefits of waste minimization and how it can be implemented in all sectors of the economy, in an effective, safe and sustainable manner [4].

The three R's are commonly used terms in waste management; they stand for "reduce, reuse, and recycle". As waste generation rates have risen, processing costs increased, and available landfill space decreased, the three R`s have become a central tenet in sustainable waste management efforts [6, 7, 8, 9]. The concept of waste reduction, or waste minimization, involves redesigning products or changing societal patterns of consumption. The most effective way to reduce waste is by not creating it in the first place, and so reduction is placed at the top of waste hierarchies [10]. In many instances, reduction can be achieved through the reuse of products. Efforts to take action to reduce waste before waste is actually produced can also be termed pre-cycling [11]. Reusing products displaces the need to buy other products thus preventing the generation of waste [12, 13]. Minimizing waste through reduction and reuse offers several advantages including; saving the use of natural resources to form new products, reducing waste generated from product disposal and reducing costs associated with waste disposal [2]. It is inevitable that waste will be created as a by-product of daily human living, but in many cases it is possible for this waste to be diverted and recycled into valuable new materials [14]. Glass, plastic and paper products are commonly collected and reformed into new materials and products in a process called recycling. Although, recycling products offer many of the benefits of waste reduction efforts (displacing new material usage, reducing waste generated and the costs associated with disposal), it requires energy and the input of some new materials, thus placing it lower on the waste hierarchy than reduction and reuse [10, 13].

2.0: Description of Study Area

The study area is Benin City. As a result of the influx of people from the rural area and neighbouring states, the city experienced tremendous expansion and developed into a metropolis. Benin City is currently the head quarter of Edo State of Nigeria and is made up of three local government areas, namely; Oredo, Egor and Ikpoba-Okha. There are three (3) geographical zones in Benin metropolis – traditional core, transitional zone and, outer zone [15].

The traditional core is the area impounded by the City moat and consists of a large percentage of old mud houses. The monarch of Benin kingdom has his palace in the traditional core zone of the metropolis. The traditional core has a high percentage of the lower social class of the population in the metropolis. The transitional Zone is the area that has been added to the traditional core due to development in Benin metropolis. This area has the largest proportion of the middle social class, followed by the lower social class and covers a large proportion of Egor and Ikpoba-Okha local government area of the metropolis. The outer zone is the periphery of Benin metropolis which consists of the sub-urban development at the fringe of the City. Among the multitude of problems existing in the metropolis, solid waste appears to be the most prominent in recent years. Solid waste is seen in huge heaps on any piece of unused land, around buildings and in the open market places. Living with solid waste littered around appears to be an acceptable way of life among the people in the metropolis in recent years. The management of solid waste did not become a phenomenon in Benin metropolis until the 1980s when there was massive influx of people as a result of industrial growth and urbanization from less developed part of Edo state and Nigeria and the national policy on environment was launched by the Federal Government on the 27th November 1989 which led to the formation of Edo State Environmental Protection Agency (EDSEPA) [16]. EDSEPA transformed into the Ministry of Environment in line with national trend on 10th April 2000 [17]. The Edo State waste management board was then created in the ministry of environment to oversee the waste management activities in the state. In addition, the environmental departments were also created in the Local government council to oversee the waste management activities at the local government level [18].

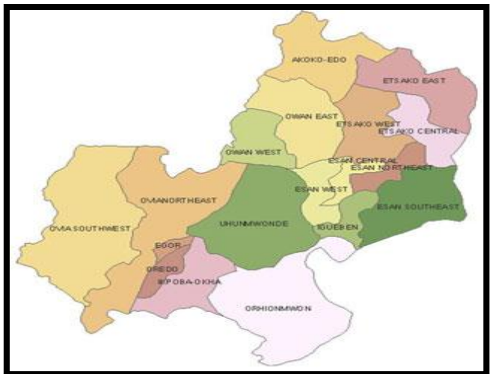


Figure 2.1: Study Area Map (Edo State Government, 2007)

3.0: Model Development/Data Collection

The overall task of the optimization model was to minimize the total cost of solid waste collection in Benin City using the 2-level factorial design of experiment. The selected variables for the optimization include:

i. The number of solid waste collection trips per month = (X_1)
ii. Number of manpower (persons) per collection vehicle= (X_2)
iii. Fuel consumption per day (for each collection vehicle) = (X_3)
iv. Weight of solid waste collected per trip= (X_4)

From the data collected from Edo State Waste Management Board, it was observed that

i. For a specific vehicle such as Tipper, the maximum number of trips per month is 50 collection trips
ii. The maximum number of workers (persons) per collection vehicle is 4
iii. The maximum fuel consumption per day is 60 liters
iv. The maximum weight of solid waste collected per trip is 10 tons
v. The monthly salary of solid waste collectors (per persons per month) is ₦27,000
vi. Cost of fuel per liter is ₦150
vii. Cost of vehicle maintenance is presented in Table 3.1;

Table 3.1: Average monthly cost of vehicle maintenance

S/No	Time (months)	Maintenance Cost (₦)
1	January	571,400
2	February	782,200
3	March	1,060,000
4	April	275,650
5	May	557,500
6	June	565,650
7	July	395,400
8	August	777,910

The overall cost function for the optimization per month was then formulated as follows

Objective function (C_f) = $(X_1) + 27{,}000(X_2) + (60X_3) + (X_4) + 45{,}000$

$$(X_1) + (X_4) \le ₦1{,}060{,}000$$
$$(X_2) \le ₦135{,}000$$
$$(X_3) \le ₦9{,}000$$

The constant in the cost function equation (₦45,000) was taken as the monthly allowance for the driver of the collection vehicle.

3.1: Design of Experiment/ Process Optimization

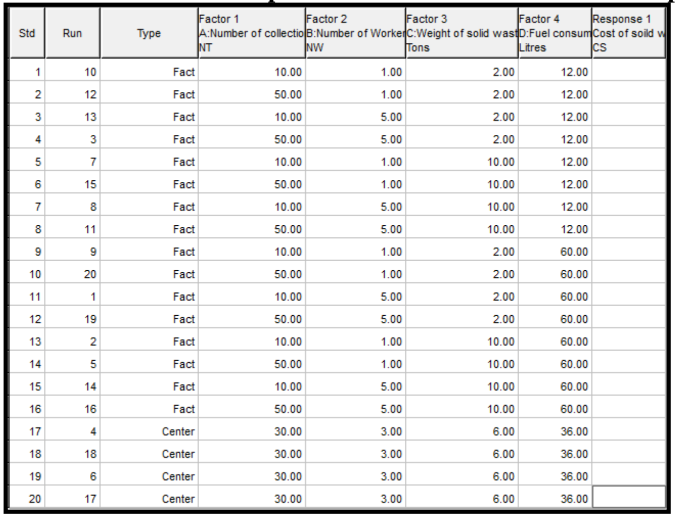
To perform the optimization, statistical design of experiment using central composite design method (CCD) was employed. The range and level of each of the selected variable is presented in Table 3.2.

Table 3.2: Range and level of experimental variables affecting solid waste collection

S/No	Variable Name	Range/Level
1	Number of collection trips per month	10 – 50
2	Number of workers per collection vehicles	1 – 5
3	Weight of solid waste collected per trip (ton)	2 – 10
4	Fuel consumption per day (liters)	12 – 60

For experimental design and process optimization, Design Expert software was employed. The number of experimental run using the CCD method was calculated as; ($N = 2^n + 2n + K$), where n is the number of variables and k is the center point. Thirty (30) experimental runs were generated and a section of the design matrix is presented in Table 3.3.

Table 3.3: Section of experimental matrix for solid waste optimization



Std	Run	Type	Factor 1 A:Number of collectio NT	Factor 2 B:Number of Worker NW	Factor 3 C:Weight of solid wast Tons	Factor 4 D:Fuel consum Litres	Response 1 Cost of soild w CS
1	10	Fact	10.00	1.00	2.00	12.00	
2	12	Fact	50.00	1.00	2.00	12.00	
3	13	Fact	10.00	5.00	2.00	12.00	
4	3	Fact	50.00	5.00	2.00	12.00	
5	7	Fact	10.00	1.00	10.00	12.00	
6	15	Fact	50.00	1.00	10.00	12.00	
7	8	Fact	10.00	5.00	10.00	12.00	
8	11	Fact	50.00	5.00	10.00	12.00	
9	9	Fact	10.00	1.00	2.00	60.00	
10	20	Fact	50.00	1.00	2.00	60.00	
11	1	Fact	10.00	5.00	2.00	60.00	
12	19	Fact	50.00	5.00	2.00	60.00	
13	2	Fact	10.00	1.00	10.00	60.00	
14	5	Fact	50.00	1.00	10.00	60.00	
15	14	Fact	10.00	5.00	10.00	60.00	
16	16	Fact	50.00	5.00	10.00	60.00	
17	4	Center	30.00	3.00	6.00	36.00	
18	18	Center	30.00	3.00	6.00	36.00	
19	6	Center	30.00	3.00	6.00	36.00	
20	17	Center	30.00	3.00	6.00	36.00	

To generate the cost function matrix, information presented in Table 3.1 were employed to produce an overall maintenance cost based on the relationship between the weight of solid waste collected per trip, the number of collection trip and the overall cost of vehicle maintenance. This overall cost function was generated based on the following assumptions;

i. The more the weight of solid waste collected, the higher the probability of vehicle breakdown and the higher the maintenance cost.

ii. The more the number of collection trips, the higher the probability of vehicle breakdown and the higher the maintenance cost.

All other assumptions not considered in obtaining the overall cost function matrix were considered as uncertainties which was resolved by the addition of an assumed variable cost X. For this design, X was taken as ₦50, 000 per month. Based on the assumptions, the overall cost function matrix was obtained.

Maximum cost of maintenance was taken based on the information of Table 3.1 as ₦1, 060, 900. The value was adopted as extreme value to represent the total cost of maintenance for maximum number of trips (50) and maximum weight of solid waste (10 tons) which resulted in frequent breakdown of the collection vehicle. In addition, a minimum cost function was adopted as ₦275, 650: which represent the total cost of maintenance for minimum number of trips (10) and minimum weight of solid waste (2 tons) which resulted in minimum numbers of breakdown of the collection vehicle.

To obtain the remaining cost of maintenance, the entire cost matrix was subjected to missing value analysis using expectation maximization algorithm. It is important to note that before you perform missing data analysis using EMA, you will need to first run the little MCAR (missing completely at random) test which include; chi-square, DF and Sig. The null hypothesis for the little MCAR test was formulated as;

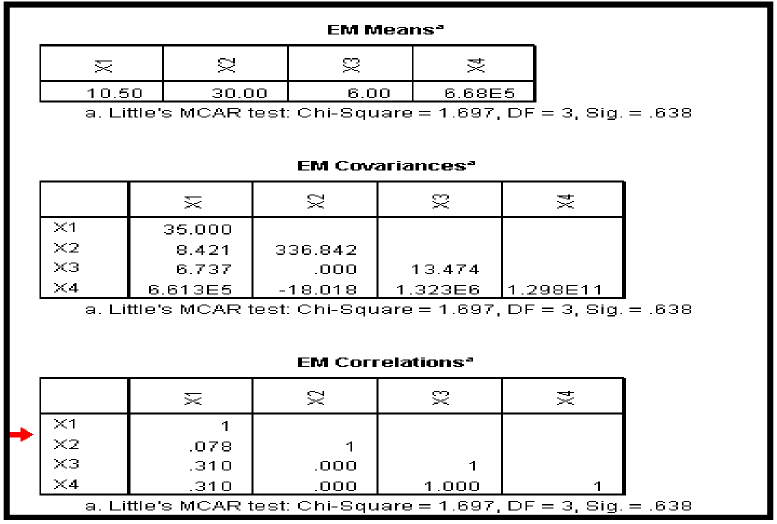
H_0; the data are missing completely at random
H_1; data are not missing completely at random

Since the analysis was done at 0.05 degree of freedom, that is 95% confidence interval, therefore if Sig > 0.05 then we accept H_0 and conclude that the data are missing completely at random then we can employ EMA to fill the missing value

4.0: Results and Discussion

Estimated statistics based on the missing value analysis using EMA is presented in Table 4.1.

Table 4.1: Expectation maximization algorithm (EMA) estimated statistics



EM Means[a]

X1	X2	X3	X4
10.50	30.00	6.00	6.68E5

a. Little's MCAR test: Chi-Square = 1.697, DF = 3, Sig. = .638

EM Covariances[a]

	X1	X2	X3	X4
X1	35.000			
X2	8.421	336.842		
X3	6.737	.000	13.474	
X4	6.613E5	-18.018	1.323E6	1.298E11

a. Little's MCAR test: Chi-Square = 1.697, DF = 3, Sig. = .638

EM Correlations[a]

	X1	X2	X3	X4
X1	1			
X2	.078	1		
X3	.310	.000	1	
X4	.310	.000	1.000	1

a. Little's MCAR test: Chi-Square = 1.697, DF = 3, Sig. = .638

From the result, of Table 4.1, it was observed that (sig = 0.638; > 0.05) hence, the null hypothesis was accepted, it was concluded that the data were missing completely at random and expectation maximization algorithm was then employed to fill the missing data. Using the cost function equation, the overall cost of solid waste collection was calculated based on the CCD design and results obtained is presented in Table 4.2

Table 4.2: Computed cost of solid waste management

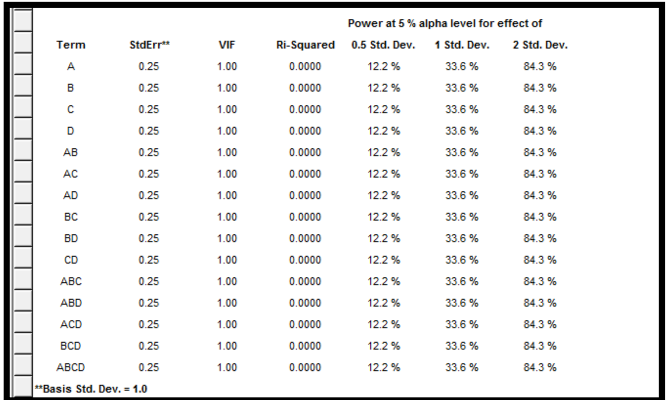
Run	Cost Computation
1	27,000(1)+150(12)+(275,650)+95,000 = 399,450
2	27,000(1)+150(12)+(275,649)+95,000 = 399,449
3	27,000(5)+150(12)+(275,650)+95,000 = 507,450
4	27,000(5)+150(12)+(275,649)+95,000 = 507,449
5	27,000(1)+150(12)+(1,060,901)+95,000 = 1,184,701
6	27,000(1)+150(12)+(1,060,900)+95,000 = 1,184,700
7	27,000(5)+150(12)+(1,060,901)+95,000 = 1,292,701
8	27,000(5)+150(12)+(1,060,900)+95,000 = 1,292,700
9	27,000(1)+150(60)+(275,650)+95,000 = 406,650
10	27,000(1)+150(60)+(275,649)+95,000 = 406,649
11	27,000(5)+150(60)+(275,650)+95,000 = 514,650
12	27,000(5)+150(60)+(275,649)+95,000 = 514,649
13	27,000(1)+150(60)+(1,060,901)+95,000 = 1,191,901
14	27,000(1)+150(60)+(1,060,900)+95,000 = 1,191,900
15	27,000(5)+150(60)+(1,060,901)+95,000 = 1,299,901
16	27,000(5)+150(60)+(1,060,900)+95,000 = 1,299,900
17	27,000(3)+150(36)+(668,275)+95,000 = 849,675
18	27,000(3)+150(36)+(668,275)+95,000 = 849,675
19	27,000(3)+150(36)+(668,275)+95,000 = 849,675
20	27,000(3)+150(36)+(668,275)+95,000 = 849,675

Result of Table 4.2 was adopted as the response variable (overall cost function) for optimizing the cost of solid waste management using numerical optimization method. Evaluation of the design model reveals that the model possesses a low standard error of 0.25 for both the individual factors and the combine interactions as presented in Table 4.3.

Standard errors should be similar within type of coefficient. Smaller is better. Ideal variance inflation factor (VIF) is 1.0. VIF's above 10 are cause for alarm, indicating coefficients are poorly estimated due to multicollinearity. Ideal Ri-squared is 0.0. High Ri-squared means terms are correlated with each other, possibly leading to poor models. From the results of Table

4.3, it was concluded that the model is significant since the VIF and Ri-squared values falls within the limit of acceptance coupled with the low values of the standard errors. VIF was observd to be 1.00, Ri-squared value was 0.00 with a standard error value of 0.25. Correlation matrix of regression coefficient is presented in Table 4.4. Lower values of the off diagonal matrix as observed in Table 4.4 indicate a well fit model that is strong enough to navigate the design space and accurately calculate the optimized cost of solid waste management while also determining the optimum values of the selected variables.

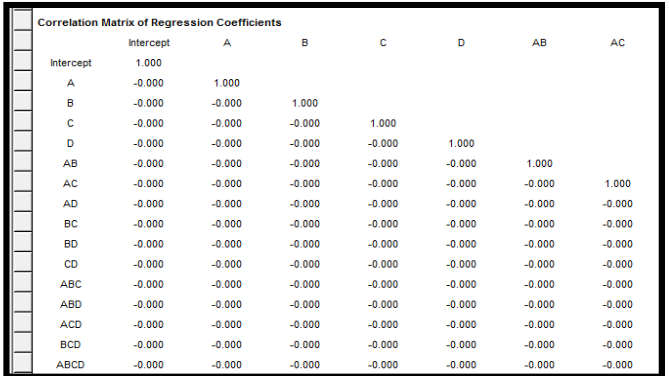
Table 4.3: Model evaluation for optimizing cost of solid waste management



				Power at 5 % alpha level for effect of		
Term	StdErr**	VIF	Ri-Squared	0.5 Std. Dev.	1 Std. Dev.	2 Std. Dev.
A	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
B	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
C	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
D	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
AB	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
AC	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
AD	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
BC	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
BD	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
CD	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
ABC	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
ABD	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
ACD	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
BCD	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %
ABCD	0.25	1.00	0.0000	12.2 %	33.6 %	84.3 %

**Basis Std. Dev. = 1.0

Table 4.4: Correlation matrix of regression coefficients for optimizing the cost of solid waste management

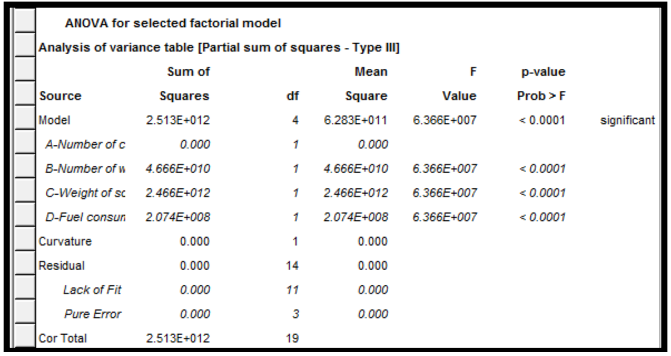


Correlation Matrix of Regression Coefficients

	Intercept	A	B	C	D	AB	AC
Intercept	1.000						
A	-0.000	1.000					
B	-0.000	-0.000	1.000				
C	-0.000	-0.000	-0.000	1.000			
D	-0.000	-0.000	-0.000	-0.000	1.000		
AB	-0.000	-0.000	-0.000	-0.000	-0.000	1.000	
AC	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	1.000
AD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
BC	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
BD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
CD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
ABC	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
ABD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
ACD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
BCD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
ABCD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000

In assessing the strength of the model to accurately predict the cost of solid waste management, one-way analysis of variance (ANOVA) was done and result is presented in Table 4.5.

Table 4.5: Assessment of model significance using analysis of variance (ANOVA)



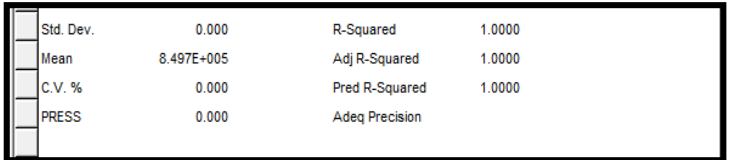
ANOVA for selected factorial model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2.513E+012	4	6.283E+011	6.366E+007	< 0.0001	significant
A-Number of c	*0.000*	*1*	*0.000*			
B-Number of w	*4.666E+010*	*1*	*4.666E+010*	*6.366E+007*	*< 0.0001*	
C-Weight of sc	*2.466E+012*	*1*	*2.466E+012*	*6.366E+007*	*< 0.0001*	
D-Fuel consur	*2.074E+008*	*1*	*2.074E+008*	*6.366E+007*	*< 0.0001*	
Curvature	0.000	1	0.000			
Residual	0.000	14	0.000			
Lack of Fit	*0.000*	*11*	*0.000*			
Pure Error	*0.000*	*3*	*0.000*			
Cor Total	2.513E+012	19				

The Model F-value of 63660000 implies that the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, D are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. Based on the above analysis, it is seen that the selected factors; number of collection trip (A), number of workers (B), weight of solid waste (C) and fuel consumption (D) all have significant influence on the overall cost of solid waste management. To validate the level of significance and adequacy of the model based on its ability to optimize the overall cost of solid waste management, the goodness of fit statistics presented in Table 4.6 was employed.

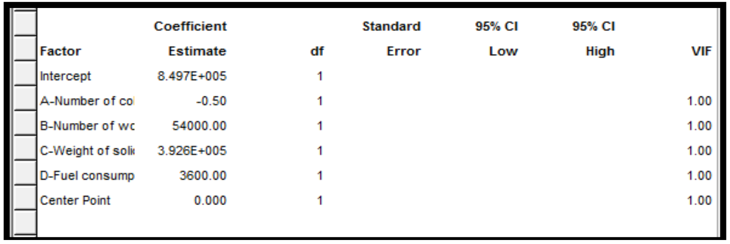
Table 4.6: Goodness of fit statistics for validating model adequacy



Std. Dev.	0.000	R-Squared	1.0000
Mean	8.497E+005	Adj R-Squared	1.0000
C.V. %	0.000	Pred R-Squared	1.0000
PRESS	0.000	Adeq Precision	

Coefficient of determination (R^2) of 1.0000 shows the strength of the model and its ability to predict the values of the selected variables that will help optimize the overall cost of solid waste management. Adj R-Squared of 1.0000 indicate 100 percentage reliability while predicted R-Squared value of 1.0000 indicates a high degree of model prediction accuracy. The reasonable agreement between the Adj R-Squared value and the predicted R-Squared coupled with a predicted error sum of square value of 0.00 shows the significant of the model and its ability to navigate the design space. To obtain the optimal equation, the coefficient statistics was first consider as presented in Table 4.7.

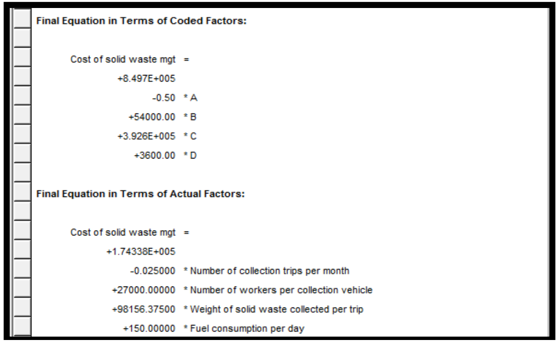
Table 4.7: Coefficient estimates statistics for optimizing cost of solid waste management



Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	8.497E+005	1				
A-Number of co	-0.50	1				1.00
B-Number of wc	54000.00	1				1.00
C-Weight of soli	3.926E+005	1				1.00
D-Fuel consump	3600.00	1				1.00
Center Point	0.000	1				1.00

The optimal equation which shows the individual effects and combine interactions of the selected factors against the mesured response (cost of solid waste management) is presented based on the coded variables and the actual factors as shown in Table 4.8

Table 4.8: Opimal equation in terms of coded and actual factors



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Final Equation in Terms of Coded Factors:

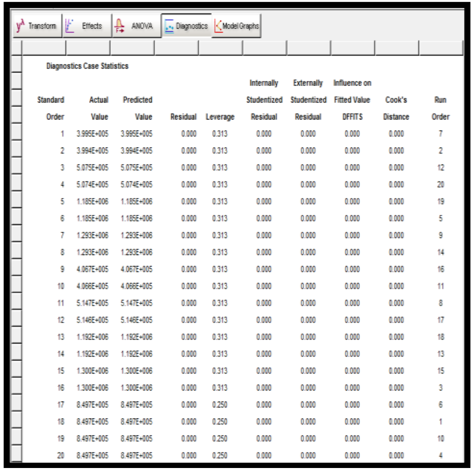
      Cost of solid waste mgt  =
               +8.497E+005
                     -0.50  * A
                 +54000.00  * B
               +3.926E+005  * C
                  +3600.00  * D

Final Equation in Terms of Actual Factors:

      Cost of solid waste mgt  =
             +1.74338E+005
                 -0.025000  * Number of collection trips per month
              +27000.00000  * Number of workers per collection vehicle
              +98156.37500  * Weight of solid waste collected per trip
                +150.00000  * Fuel consumption per day
```

The diagnostics case statistics which shows the computed cost of solid waste management against the predicted cost is presented in Table 4.9

Table 4.9: Diagnostics case statistics for optimizing cost of solid waste management



Diagnostics Case Statistics

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Influence on Fitted Value DFFITS	Cook's Distance	Run Order
1	3.995E+005	3.995E+005	0.000	0.313	0.000	0.000	0.000	0.000	7
2	3.994E+005	3.994E+005	0.000	0.313	0.000	0.000	0.000	0.000	2
3	5.075E+005	5.075E+005	0.000	0.313	0.000	0.000	0.000	0.000	12
4	5.074E+005	5.074E+005	0.000	0.313	0.000	0.000	0.000	0.000	20
5	1.185E+006	1.185E+006	0.000	0.313	0.000	0.000	0.000	0.000	19
6	1.185E+006	1.185E+006	0.000	0.313	0.000	0.000	0.000	0.000	5
7	1.293E+006	1.293E+006	0.000	0.313	0.000	0.000	0.000	0.000	9
8	1.293E+006	1.293E+006	0.000	0.313	0.000	0.000	0.000	0.000	14
9	4.067E+005	4.067E+005	0.000	0.313	0.000	0.000	0.000	0.000	16
10	4.066E+005	4.066E+005	0.000	0.313	0.000	0.000	0.000	0.000	11
11	5.147E+005	5.147E+005	0.000	0.313	0.000	0.000	0.000	0.000	8
12	5.146E+005	5.146E+005	0.000	0.313	0.000	0.000	0.000	0.000	17
13	1.192E+006	1.192E+006	0.000	0.313	0.000	0.000	0.000	0.000	18
14	1.192E+006	1.192E+006	0.000	0.313	0.000	0.000	0.000	0.000	13
15	1.300E+006	1.300E+006	0.000	0.313	0.000	0.000	0.000	0.000	15
16	1.300E+006	1.300E+006	0.000	0.313	0.000	0.000	0.000	0.000	3
17	8.497E+005	8.497E+005	0.000	0.250	0.000	0.000	0.000	0.000	6
18	8.497E+005	8.497E+005	0.000	0.250	0.000	0.000	0.000	0.000	1
19	8.497E+005	8.497E+005	0.000	0.250	0.000	0.000	0.000	0.000	10
20	8.497E+005	8.497E+005	0.000	0.250	0.000	0.000	0.000	0.000	4

Lower residual values resulting to lower leverages as observed in Table 4.9 are indicators of a well fitted model. The model graphs which shows the interactions of combine variables on the measured response (cost of solid waste management) was evaluated using the 3D surface plot as presented in Figures 4.1 and 4.2 respectively

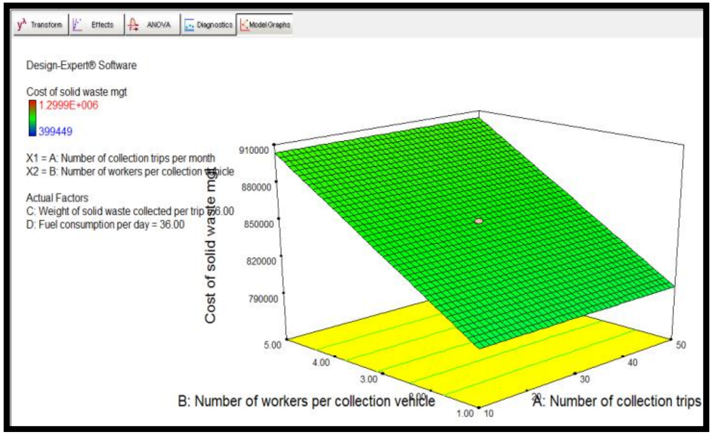


Figure 4.1: Influence of number of workers per collection vehicle and number of collection trips on the overall cost of solid waste management

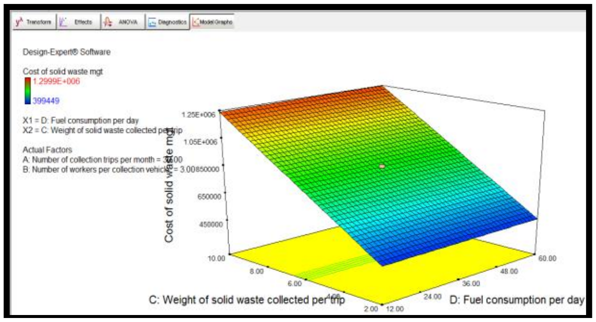
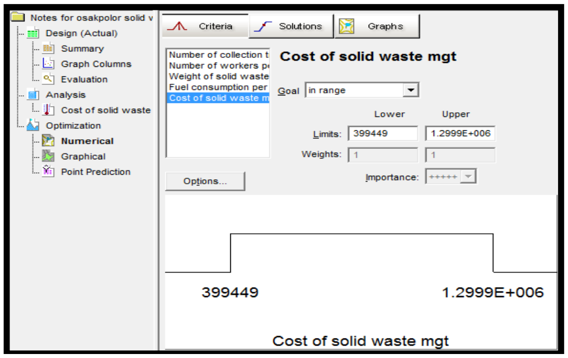


Figure 4.2: Influence of weight of solid waste collected and fuel consumption on the overall cost of solid waste management

The 3D surface plot shown in Figures 4.1 and 4.2 was used to assess the prediction bound for the optimization design model and to evaluate the relative influence of each variable on the overall cost function. From the plots of Figures 4.1 and 4.2, it was observed that weight of solid waste collected and fuel consumption have higher influence on cost function than numbers of workers and numbers of collection trip. Finally, numerical optimization was performed to ascertain the desirability of the overall model. In the numerical optimization phase, we ask design expert to optimize the overall cost of solid waste management in order to determine the optimal value of the number of collection trip (A), number of workers (B), weight of solid waste (C) and fuel consumption (D). The interphase of the numerical optimization model is presented in Figure 4.3



Cost of solid waste mgt

Goal: in range

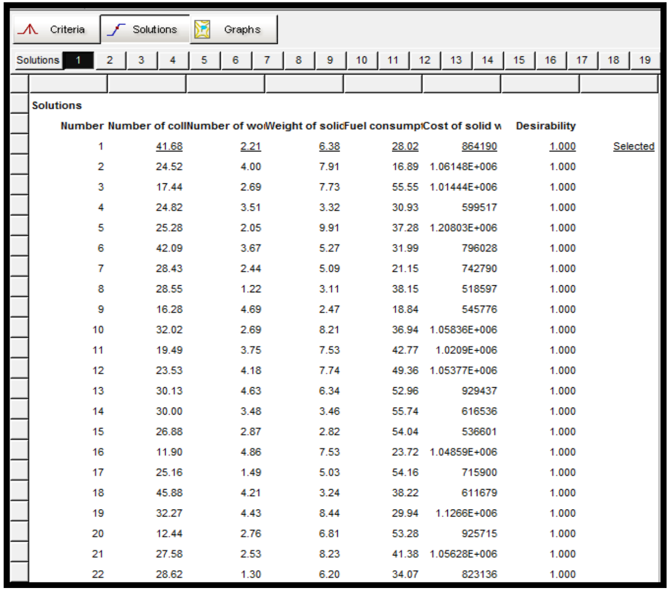
	Lower	Upper
Limits:	399449	1.2999E+006
Weights:	1	1

Importance: +++++

Figure 4.3: Interphase of numerical optimization model for optimizing the cost of solid waste management

The numerical optimization produces about 30 optimal results, 22 of them are presented in Table 4.10

Table 4.10: Optimal solutions of numerical optimization model



Solutions

Number	Number of coll	Number of wo	Weight of solid	Fuel consumpt	Cost of solid w	Desirability	
1	41.68	2.21	6.38	28.02	864190	1.000	Selected
2	24.52	4.00	7.91	16.89	1.06148E+006	1.000	
3	17.44	2.69	7.73	55.55	1.01444E+006	1.000	
4	24.82	3.51	3.32	30.93	599517	1.000	
5	25.28	2.05	9.91	37.28	1.20803E+006	1.000	
6	42.09	3.67	5.27	31.99	796028	1.000	
7	28.43	2.44	5.09	21.15	742790	1.000	
8	28.55	1.22	3.11	38.15	518597	1.000	
9	16.28	4.69	2.47	18.84	545776	1.000	
10	32.02	2.69	8.21	36.94	1.05836E+006	1.000	
11	19.49	3.75	7.53	42.77	1.0209E+006	1.000	
12	23.53	4.18	7.74	49.36	1.05377E+006	1.000	
13	30.13	4.63	6.34	52.96	929437	1.000	
14	30.00	3.48	3.46	55.74	616536	1.000	
15	26.88	2.87	2.82	54.04	536601	1.000	
16	11.90	4.86	7.53	23.72	1.04859E+006	1.000	
17	25.16	1.49	5.03	54.16	715900	1.000	
18	45.88	4.21	3.24	38.22	611679	1.000	
19	32.27	4.43	8.44	29.94	1.1266E+006	1.000	
20	12.44	2.76	6.81	53.28	925715	1.000	
21	27.58	2.53	8.23	41.38	1.05628E+006	1.000	
22	28.62	1.30	6.20	34.07	823136	1.000	

Based on the numerical optimization analysis, the following optimal results were obtained;

i. Number of collection trip (NT) = 42
ii. Number of workers (NW) = 2
iii. Weight of solid waste (C) = 6.38tons
iv. Fuel consumption (D) = 28.02 liters

These optimal solutions of selected variables resulted in an overall cost of N864, 190. The solution was selected by design expert as the optimal solution having a desirability value of 1.000 that is 100% reliability. The ramp solution, which is the graphical presentation of the optimal solution, is presented in Figure 4.4.

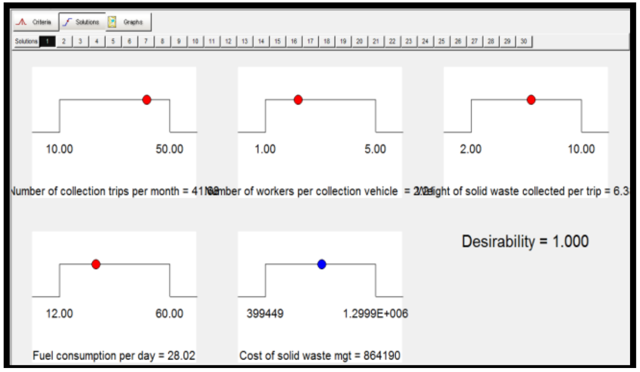


Figure 4.4: Ramp solution of numerical optimization

5.0: Conclusion

In this study, the potential of statistical design of experiment and response surface methodology in optimizing a given solid waste management system have been evaluated. Results of the analysis have shown that a combination of design of experiment and numerical optimization is effective in determining the optimal values of solid waste variables and computing the overall cost function. At 0.05df, result of the one-way analysis of variance shows that the optimization model is highly significant with p-value < 0.0001 as observed in Table 4.5. The accuracy of the model was further established using the goodness of fit statistics presented in Table 4.6 in which the computed coefficient of determination (R^2) was observed to be 1.000. Although, the content of this study is not completely exhaustive on the subject matter, it has provided addition information to the existing literatures on modelling and optimization of solid waste management systems.

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