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Research Paper

Mathematical Model And The Economic Analysis of Solid Waste Disposal In Aba Metropolis

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ABSTRACT: *In Kalu et al. (2017) we looked at Mathematical Model of Municipal solid waste management system in Aba metropolis of Abia State of Nigeria. In this particular paper we carried out the economic analyzed the solid waste disposal in Aba. We analyzed the data collected in Kalu, et al. (2017). When the effect of the capacity of the collection center was carried out, it was observed that minimum cost falls with rise in capacity of the collection centre. It is seen that the number and permutation of collection centres to be opened for minimum cost of the transportation network is independent of the scavenged fraction, but the quantities moved* x_{ij} *and* y_{jk} *at optimal and the minimum transportation cost is affected by scavenged fraction. These results confirm the expectation that rise in scavenged fraction will cause a fall in minimum transportation cost and the quantities moved to the landfills. The analysis further reveals that when the collection centers are designed to have the maximum capacities of C=350 with other factors being equal, the minimum cost becomes ₦3,948,700.00 and 7 out of the 15 collection centers are open and thus in use. It is also seen that the best way to minimize the burden of payment on the customers while guaranteeing reasonable daily profit to the investor and tax return to the government is to increase the capacity of the collection centers and optimal place to locate them.*

Keywords: *Solid waste, Solid Waste Disposal, Municipal waste management, Economic Analysis, Scavenged Fraction*

I. INTRODUCTION

Solid waste management is a global issue that is a growing source of concern in developed and developing countries due to increase urbanization; changes in consumer pattern and industrialization which all directly influence solid waste generally. Kadafa et al (2013). Adedibu (1993) is of the view that the nature and composition of solid waste is a product of climatic and business activities in urban centers. He argue further that most of the agricultural produce such as maize, cassava, vegetable, millet are brought unprocessed during the rainy and harvesting seasons from the nearby farms. The composition of refuse generated in an area determines the type of disposal method suitable for a particular form of waste and the effectiveness of a collection system depends on the cooperation of households and individuals in various sectors of the city in providing containers for storing refuse in accordance with the regulation and regularly placing the materials for collection, Afon (2003). Abumere (1983) links socio-cultural factors to land use pattern such as housing density and eating habits. He further states that solid waste accumulation is a product of chaotic land use pattern, the number of household living and that the eating habit in a house greatly determines the composition of refuse generated. Abila and Kantola (2013) are of the view that municipal waste management problems in Nigeria cut across concern for human health, air and water and land pollution among others. Adewole (2009) argue that continuous indiscriminate disposal of municipal solid waste is accelerating and is linked to poverty, poor governance, urbanization, population growth, poor standard of living and low level of environmental awareness.

Daskalopoulos et al (1998) have presented a mixed integer linear programming model for the management of MSW streams. This is similar to our model. The cost in the objective function of their model caters for the environmental considerations related to the emission of greenhouse gases. This is also similar to our model. Unlike our model, Daskalopoulos, et al (1998) does not cover collection and transportation costs. Regulatory and technical constraints are not considered either.

Badran and El-Haggar (2005) studied optimization of solid waste management systems using operation research methodologies. A mixed integer linear programming model is a problem whose objective covers collection costs from the districts to collection stations, transportation costs from collection stations to their composting plants or to landfills. This is similar to our model. Unlike our model, their model did not cater for environmental considerations related to the emission of greenhouse gases.

The model of Chang and Chang (1998) minimizes overall cost through the solution of a nonlinear programming problem. Unlike our model, their model does not cater for regulatory and environmental constraints. We present linear model and go at length in estimation of environmental hazard cost and scavenged fraction. Costi, et al (2004) have presented a comprehensive mixed integer nonlinear programming problem, whose planning horizon is a year. They give a detailed description of environmental constraints that cover Refuse Derived Fuel (RDF) constraints, incineration constraints and Stabilized Organic Material (SOM) constraints. The nonlinearity of their model consists in the nature of the decision variables used. These decision variables are percentages (fractions) of waste that has to be sent to various plants and landfills in their model. The interaction between these percentages generates their products that appear in the objective function, in the regulatory (normative) constraints, in the technical and environmental constrains. One of the differences between Costi et al (2004) model and our model is that while the planning horizon of Costi et al (2004) is one year, the planning horizon of our model is a day; decisions are to be taken on a day to day basis. This means a continuous monitoring and collection data in order to make the required adjustments. This flexibility may be lost in a long period horizon model. In contrast to Costi et al (2004) model which is non linear, our model is linear. Again, another differences between Costi et al (2004) and our model is that while our model accounts for the collection cost from waste sources to collection points. This is not part of their model.

Halidi (2011) has presented a mixed integer programming of municipal solid waste management in Ilala municipality. He uses the concept of having collection centers. The proposed model results in a least transportation cost T_{sh} 10, 969,252 per day compared with the one given by Ilala municipality of T_{sh} 14,000,000per day. Furthermore, the study shows that any additional increase of the collection centre capacity up to 500 tons will result in a decrease of the objective function value. One of the limitations of Halidi (2011) is that he did not incorporate environmental hazard cost and scavenged fraction into the model. The cost in the objective function of our model caters for the environmental consideration related to the emission of greenhouse gases (GHGS) that cause global warming. We also estimated the scavenged fraction.

The total cost of the solid waste management system include the transportation cost of the waste to different facilities such as transfer stations, landfills, incinerators and also the operational and fixed costs of these facilities Badaran and El-Haggar (2006). The management of solid waste has been a primary function of the municipal/local government in each state; however, attaining efficiency in the sector has been a major challenge especially in the prominent cities within the country such as Aba, Enugu, Owerri, Port-Harcourt, Kaduna, Lagos and Ibadan where piles of Municipal Solid Waste (MSW) are often observed. Idowu et al (2011), their sources being households, markets and places of commercial activity, Momodu (2011).

Hasit and Warner (1981) compared these two techniques when applied to the waste resource allocation programme model. In their scenarios, the number of cost combinations increased rapidly as the number of facilities increased, resulting in higher data requirements and programme handling. They noted that linear programming models can get offset by those effects and cannot handle discrete sizes for facilities. Instead, they added mixed integer programming which can take all those considerations into account. In the municipality of Genova, Italy, Costi, et al (2004) have proposed a mixed integer non-linear programming decision support model to help decision makers of a municipality in the development of incineration, disposal, treatment and recycling integrated programs. Chang and Chang (1998) have presented a non-linear programming model for municipal solid waste management based on the minimization of an overall cost considering energy and material recovery requirements.

In the paper Kalu, et al (2017) we developed the Mathematical Model of Municipal Solid Waste Management System in Aba Metropolis. We developed the model and analyzed the model. In this particular work, we analyzed the economic implication of the solid waste disposal in Aba metropolis of Abia State, Nigeria. We recall that the model developed in Kalu, et al (2017) is as presented in (1.1) below.

$$\left.\begin{aligned}
&Min.Z(Q,X,Y)=\sum_{j=1}^{15}(F_j+hC_j)Q_j+\sum_{i=1}^{90}\sum_{j=1}^{15}T_{ij}x_{ij}+\sum_{j=1}^{15}\sum_{k=1}^{3}T_{jk}y_{jk}\\
&\text{Subject to:}\\
&\sum_{j=1}^{15}x_{ij}=W_i,\ i=1,2,3,\dots,90\\
&(1-f)\sum_{i=1}^{90}\sum_{j=1}^{15}x_{ij}=\sum_{j=1}^{15}\sum_{k=1}^{3}y_{jk},\ i=1,2,3,\dots,90\\
&(1-f)\sum_{i=1}^{90}x_{ij}\le C_j\ (j=1,2,3,\dots,15)\\
&\sum_{j=1}^{15}y_{jk}\le L_k,\ k=1,2,3\\
&\sum_{j=1}^{15}Q_j\le N\\
&\sum_{j=1}^{15}Q_jC_j\ge\sum_{i=1}^{90}W_i\\
&x_{ij}\ge 0,\ y_{jk}\ge 0,\ i=1,2,3,\dots,90;\ j=1,2,3,\dots,15;\ k=1,2,3
\end{aligned}\right\}\qquad(1.1)$$

II. DATA PRESENTATION

Data were collected for the study as follows:

Table 2.1: Amount of Solid Waste Generated/Day from Different Streets/Wards in Aba Metropolis.

	SOURCES	Notation	Waste (Ton/Day)	Notation	SOURCES	Notation	Waste (Ton/Day)
S01	EZIAMA HIGH SCHOOL	AN01	36	S46	EHI ROAD PRIMARY SCH.	AS21	36
S02	EZIAMA CENTRAL HIGH SCH.	AN02	40	S47	ETCHE RD PRIMARY SCH	AS22	36
S03	NGWA CULTURAL HALL	AN03	32	S48	DANFODIO RD PRIMARY SCH	AS23	24
S04	OLD POST OFFICE	AN04	37	S49	ABA TOWN HALL	AS24	21
S05	OSUSU PRIMARY SCHOOL	AN05	26	S50	HOSPITAL RD PRIMARY SCH	AS25	23
S06	OKIGWE PRIMARY SCHOOL	AN06	26	S51	ABAYI COM.PRIMARY SCH	OB01	22
S07	OSUSU SECONDARY SCHOOL	AN07	21	S52	EHERE COMM.PRIMARY SCH	OB02	32
S08	HOLY GHOST COMM.SCH.	AN08	17	S53	UMUAFOR CIVIC HALL	OB03	19
S09	ST EUGEN'S PRIMARY SCHOOL	AN09	20	S54	UMUOPARA VILLA SQUARE	OB04	15
S10	URATTA COUNCIL HALL	AN10	21	S55	UMUAGBA CIVIL HALL	OB05	11
S11	STELLA MARIS SEC SCH.	AN11	18	S56	ITUNGWA CPS	OB06	10
S12	GULF COURSE PRIMARY SCH	AN12	20	S57	UMUHU ALAOJI HALL	OB07	23
S13	WATER TANK PREMISES	AN13	23	S58	UMUOKEREKE-UHIE COURT	OB08	16
S14	UMUOLA OKPULOR HALL	AN14	27	S59	IHEOJI / UMUOJIMA	OB09	33
S15	UMUOLA EGBELU HALL	AN15	18	S60	MBOKO -OKPULOR HALL	OB10	14
S16	BTC SCHOOL PREMISES	AN16	40	S61	UMUOBIKWA	OB11	14
S17	OLD INTERNAL REVENUE PREMISES	AN17	42	S62	OHANZE CPS	OB12	18
S18	EZIOBI PRIMARY SCHOOL	AN18	37	S63	OVOM GIRLS SEC SCH	OB13	40
S19	SACRED HEART COLLEGE	AN19	32	S64	UMUOMASI	OB14	21
S20	WILCOX MEMORIAL SCHOOL	AN20	37	S65	UMUOMAI VILLAGE HALL	OB15	17
S21	NEW UMUAHIA ROAD PRIMARY SCH	AN21	22	S66	UMUOGELE CPS NTIGHAUZO	OB16	24
S22	OGBOR HILL PRIMARY SCHOOL	AN22	16	S67	OHANZE AGWO-MKT	OB17	38
S23	FEDERAL HOUSING ESTATE	AN23	21	S68	ABIAK VILLAGE HALL	OB18	20
S24	UMUOGOR / UMUASOKE HALL	AN24	24	S69	UMUOKIRIKA VILLA SQUARE	OS01	19
S25	ASA OKPULOR COUNCIL HALL	AN25	19	S70	ABAYI ARIARIA PRY SCH.	OS02	41
S26	EZIUKWU OKIGWE RD PRY SCH.	AS01	26	S71	UMUOJIMA OGBU PRY SCH	OS03	20

S27	EZIUKWU EBENATOR (OMUMA)	AS02	26	S72	UMUNGASI POST OFFICE	OS04	36
S28	EZIUKWU ASA OKPUAGA HALL	AS03	23	S73	NGWA HIGH SCHOOL	OS05	32
S29	ASA-OSUMENYI HALL	AS04	31	S74	OKPUALA-ARO VILLA HALL	OS06	8
S30	ABA TOWNSHIP PRIMARY SCH.	AS05	20	S75	UMUIHUOMA VILLAGE HALL	OS07	17
S31	ENYIMBA- ISIEKENESI HALL	AS06	41	S76	OKPUALA-UKWU COMM. SCH.	OS08	12
S32	ENYIMBA- ABAUKWU VILLAGE HALL	AS07	28	S77	IBIBI URATTA COUNCIL HALL	OS09	15
S33	NGWA-NDOKI ROAD PRIMARY SCH.	AS08	37	S78	UMUAGBAI COMM.SCH	OS10	11
S34	NGWA-IHIOMA HALL	AS09	17	S79	UMUMBA-UMURU COMM SCH	OS11	17
S35	NGWA UMUAGBAI EAST PRY SCH	AS10	20	S80	UMUABA VILLAGE HALL	OS12	10
S36	OHAZU /AKOLI HALL	AS11	16	S81	ANIGWE PRIMARY SCHOOL	UG01	26
S37	OHAZU / AWKUZU HALL (NGWA RD)	AS12	15	S82	UGWUNAGBO CUSTOM COURT	UG02	18
S38	OHAZU / IHIEORJI SEC SCH.	AS13	15	S83	AMAPU IDEOBIA PRY SCH.	UG03	22
S39	IGWEBUIKE- OHABIAM SEC SCH.	AS14	20	S84	OWERE ABA PRIMARY SCH.	UG04	14
S40	IGWEBUIKW-NNENTU VILLA HALL	AS15	17	S85	AKAMU NGWA HIGH SCH.	UG05	12
S41	ASA ROAD PRIMARY SCH.	AS16	48	S86	ASA UMUKWA PRIMARY SCH.	UG06	10
S42	ST.JOSEPH'S SCH. COLLEGE	AS17	40	S87	ASA NNETU MOTOR PARK MKT	UG07	31
S43	MARKET ROAD PRIMARY SCH.	AS18	28	S88	ALAOJI VILLAGE HALL	UG08	17
S44	OLD COURT PRIMARY SCH.	AS19	18	S89	IHIEOBEAKU PRIMARY SCH	UG09	8
S45	SCHOOL OF HEALTH	AS20	27	S90	NGWAIYIEKWE BUS STOP	UG10	20

Table 2.2: Transportation Cost Matrix (N) of Solid Waste from Sources to the Collection Centres.

	J	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13	C14	C15
I	SOURCES	AN05	AN10	AN16	AN25	AS03	AS07	AS15	AS21	OB01	OB05	OB13	OS02	OS03	OS12	UG05
S01	AN01	1280	1680	800	2240	1200	1600	1760	1040	1280	1440	1360	1440	1760	1840	2400
S02	AN02	1120	1520	880	2160	1360	1520	1600	1120	1200	1360	1440	1600	1920	1680	2480
S03	AN03	1440	1040	800	1680	880	1120	1360	720	1520	1600	1760	1760	2000	1840	3040
S04	AN04	960	560	720	1760	800	400	1200	320	1200	1360	1440	1520	1680	1600	2640
S05	AN05	0	1200	480	1440	1520	1600	1760	800	960	1760	2240	1360	2320	1600	2560
S06	AN06	880	1120	400	1600	1280	1040	1360	1200	800	960	1040	1440	1680	1920	2000
S07	AN07	400	800	720	1200	1360	1920	1200	1520	880	1680	2480	1520	2160	1440	2320
S08	AN08	560	880	560	1360	1120	960	1360	1040	960	1520	1360	1200	1520	1360	2000
S09	AN09	720	800	320	960	1040	1040	1440	1120	880	1360	1200	1360	1440	1520	1920
S10	AN10	1200	0	2000	2320	1920	1920	2080	960	2000	1920	2320	2400	2800	2560	2160
S11	AN11	1360	240	1920	2240	1360	1040	1520	800	1840	1760	2080	2240	2000	2080	1920
S12	AN12	800	1200	640	1520	960	800	1200	560	1040	1280	1440	1760	2160	2000	2000
S13	AN13	880	1120	720	1440	880	400	1040	560	1280	1360	1520	1920	2080	1840	2320
S14	AN14	1680	1440	1280	1840	1200	1360	1120	1280	1520	1760	1680	2080	2240	2000	2400
S15	AN15	1440	1360	1200	1600	720	960	880	0	1600	1680	1840	2000	1760	1680	2480
S16	AN16	480	2000	0	1760	1280	1520	1600	720	800	1600	2560	1200	2080	1440	2400
S17	AN17	1120	720	400	880	1520	1200	1440	1600	720	1120	1360	1440	1280	1600	2560
S18	AN18	960	880	800	1200	1680	1360	1760	1280	1360	1200	1520	1600	1760	1920	2720
S19	AN19	1120	1200	560	1440	1440	1520	1360	1680	1280	1520	1360	1200	1440	1600	2320
S20	AN20	1600	1280	1360	1520	1600	720	1520	1280	1600	1440	1520	1760	1680	2000	2480
S21	AN21	1520	1440	1200	1600	1440	1200	1600	1840	1840	1840	2000	1920	2000	1840	2400
S22	AN22	1680	1360	1600	1520	1680	1120	1520	1440	2000	2160	1920	2000	2160	2320	2640
S23	AN23	2240	2400	1840	2320	1920	1520	1600	1760	2160	1920	1760	2400	2240	2320	2320
S24	AN24	2000	1680	1760	1840	1760	1840	1520	1680	1680	1840	1520	2160	2000	2240	2400
S25	AN25	1440	1680	1760	0	1760	1760	1840	1120	1360	1680	2080	1760	2160	2000	2160
S26	AS01	1280	1600	1360	1920	2080	880	1280	1520	1440	1600	1840	1520	1760	2000	2560
S27	AS02	1120	1440	800	1440	560	960	1200	1360	1280	1520	1680	1200	1360	1600	2480
S28	AS03	1520	1920	1280	1760	0	1040	1600	1200	1600	1440	1840	2240	2080	1760	2320
S29	AS04	1840	1680	1200	1520	720	800	1200	1360	1680	1840	1760	2080	1920	2160	2160
S30	AS05	960	1280	720	1120	640	960	1360	1280	1280	1440	1520	1520	1440	1600	2400
S31	AS06	880	1520	800	1200	960	320	1040	1200	1520	1760	1920	2160	2000	2240	2560
S32	AS07	1600	1920	1520	1760	1040	0	1520	1440	1760	1600	1200	2640	2000	2000	2400
S33	AS08	1440	2000	1440	1520	1200	1520	1360	1280	1920	1680	2160	2400	2240	2480	2480
S34	AS09	1280	1680	1120	1440	1120	1360	1200	1360	1840	1840	2000	2320	2400	2240	2640
S35	AS10	1600	2000	1280	1840	1600	1440	1280	1200	2000	1920	2080	2160	2320	2080	2480
S36	AS11	1360	1680	1200	1600	1520	1600	1440	1600	2160	2000	2240	2080	2240	2480	2720
S37	AS12	2000	960	1600	1760	1680	1520	1760	960	2080	2240	2160	2240	2160	2400	2880
S38	AS13	2640	1440	2400	1680	2080	1680	1520	1360	2160	2240	1920	2320	2080	2240	2800
S39	AS14	2800	1600	2560	2400	2240	2160	2000	1520	2320	2160	2240	2400	2480	2320	2960
S40	AS15	1760	2080	1600	1840	1600	1520	0	1600	1680	1360	1520	2080	2160	1760	2640
S41	AS16	1520	560	960	1520	1360	1200	880	400	1760	1440	1520	2160	2000	2160	2960
S42	AS17	1120	720	800	1040	800	960	720	640	1600	1360	1440	1920	1840	2000	2720
S43	AS18	1040	640	800	1440	1120	1360	1200	320	1440	1600	1680	1840	1680	1920	2560
S44	AS19	960	800	720	1280	1040	880	960	560	1280	1360	1440	1520	1360	1440	2720
S45	AS20	880	800	640	1360	1280	1520	1360	480	1360	1520	1600	1440	1600	1520	2880
S46	AS21	800	960	720	1120	1200	1440	1600	0	1920	1680	1680	2480	2400	1920	2560

S47	AS22	960	1040	720	1440	800	1120	960	320	1760	1520	1440	2080	2160	2000	2400
S48	AS23	1120	1360	960	1280	1200	1040	560	400	1840	1600	1760	1760	1840	2080	2320
S49	AS24	960	1280	560	1040	720	640	800	480	1360	1280	1520	1360	1440	1280	1920
S50	AS25	1040	1200	800	1280	1200	960	800	240	1600	1760	2000	1600	1760	2000	2160
S51	OB01	960	2000	800	1360	1600	1760	1680	1920	0	960	1360	720	1600	1680	2240
S52	OB02	1600	1680	1440	1760	1280	800	1200	1280	2000	1840	2160	1760	1680	1920	2320
S53	OB03	1520	1600	1360	1520	1120	1520	1360	1600	1600	1760	1920	1680	1600	1760	2560
S54	OB04	1920	1840	1680	1760	1360	1680	1600	1760	1680	1840	1760	1600	1760	1680	2480
S55	OB05	1760	1920	1600	1680	1440	1600	1360	1680	960	0	1280	1680	1840	1760	2400
S56	OB06	2160	640	1920	2320	1520	1760	1600	1840	1680	1520	1840	1920	2000	2160	2240
S57	OB07	2080	560	2000	2080	2560	2240	1920	1600	2000	1760	1600	2240	2080	1920	2400
S58	OB08	2160	800	1920	1840	2240	2000	2160	2080	1920	1680	1920	2160	2240	2080	2560
S59	OB09	1760	960	1600	1520	1600	2160	2000	2400	1760	1920	2000	2400	2320	2480	2720
S60	OB10	2480	1200	2320	800	1760	2080	2160	2560	1360	1520	1680	2320	2480	2560	2800
S61	OB11	2800	1600	2560	1520	1920	2160	2320	2080	1520	1600	1440	2400	2560	2480	2960
S62	OB12	2640	1760	2400	1920	2160	2240	2080	2240	1600	1760	1680	2240	2400	2560	2720
S63	OB13	2240	2320	2560	2080	1840	1200	1520	1680	1360	1280	0	2160	2480	2400	2880
S64	OB14	2480	2240	2320	2240	2160	1840	2080	2240	1200	1600	1520	2400	2320	2480	2560
S65	OB15	2400	2080	2320	2000	2080	2160	2240	2080	1440	1760	1920	2240	2400	2160	2960
S66	OB16	2160	2560	2720	2160	2400	2160	2320	2560	2240	2000	2080	2400	2320	2480	2640
S67	OB17	2560	2720	2880	2240	2320	2240	2080	2000	2160	2320	2400	2560	2480	2640	2560
S68	OB18	2880	2480	2640	2160	2480	2160	2320	2240	1600	2240	2160	2160	2400	2320	2480
S69	OS01	2480	2960	2400	2320	1600	1920	1760	2160	1200	1520	1920	1120	1360	1760	2320
S70	OS02	1360	2400	1200	1760	2240	2640	2080	2480	720	1680	2160	0	720	560	2480
S71	OS03	1600	2480	1360	1600	2400	2800	2320	2720	800	1120	1760	400	800	960	2640
S72	OS04	720	2000	560	1280	960	1360	1200	1520	560	880	1600	960	1200	1280	2400
S73	OS05	1360	2560	1120	1680	1520	1920	1680	2080	240	1200	2160	800	1120	1360	2720
S74	OS06	2400	2720	2160	1920	1760	1920	2080	2240	640	1120	2080	1120	1040	800	2880
S75	OS07	2320	2800	2080	2160	2080	2000	2160	2400	1600	1840	2480	720	0	960	2240
S76	OS08	2160	2640	2000	2320	2240	2160	2320	2160	1200	1520	1680	960	1120	1200	2800
S77	OS09	2480	2560	2400	2640	1920	2080	1760	1840	1600	2080	2000	1600	1440	1760	2640
S78	OS10	2320	2720	2080	2400	2000	1760	2080	2160	1280	1360	1760	1680	1520	1600	2720
S79	OS11	2560	2880	2400	2240	2160	2080	1920	2000	1440	1680	1920	1520	1360	1280	2880
S80	OS12	1600	2560	1440	2000	1760	2000	1760	1920	1680	1760	2400	560	960	0	2400
S81	UG01	2880	1760	2720	2400	2560	2480	2320	2400	2080	1840	1920	2320	2400	2240	1120
S82	UG02	2720	1840	2480	1680	2720	2560	2480	2640	2160	1920	2160	2160	2320	2080	640
S83	UG03	2640	1920	2560	1920	2560	2640	2320	2480	2400	2480	2320	2480	2560	2240	1200
S84	UG04	2720	2080	2480	2400	2400	2320	2480	2400	2480	2400	2560	2400	2320	2480	960
S85	UG05	2560	2160	2400	2160	2320	2400	2560	2560	2240	2400	2880	2480	2240	2400	0
S86	UG06	2560	2240	2320	2320	2720	2480	2560	2400	2400	2560	2640	2400	2160	2320	720
S87	UG07	2720	2320	2720	2400	2320	2480	2640	2800	2320	2400	2560	2480	2160	2080	800
S88	UG08	2960	2240	2880	2080	2400	2640	2320	2560	2480	2560	2320	2320	2080	2240	960
S89	UG09	2640	1600	2800	2320	2480	2400	2560	2640	2400	2320	2560	2400	2320	2480	1120
S90	UG10	2800	2400	2720	2480	2560	2320	2720	2800	2480	2640	2800	2560	2240	2880	720

Table 2.3: Distances (km) from the Collection Centres (j) to the Landfills (k).

		K	L1	L2	L3
J	Collection Centres	Notation	Umuhu Alaoji (Ob07)	Okpuala Aro(Os06)	Ngwaiyiekwe (Ug10)
C01	Osusu	An05	13	20	22
C02	Uratta	An10	10	16	14
C03	Btc	An16	15	13	23
C04	Asa Okpulor	An25	9	11	16
C05	Eziukwu Asa Okpuaga	As03	18	23	16
C06	Enyimba-Abaukwu	As07	13	17	10
C07	Igwebuike Nnentu	As15	17	20	19
C08	Ehi Road	As21	20	16	14
C09	Abayi	Ob01	8	23	27
C10	Umuagba	Ob05	5	27	24
C11	Ovom	Ob13	14	20	16
C12	Abayi Ariaria	Os02	19	8	11
C13	Umuojima Ogbu	Os03	14	7	14
C14	Umuaba	0s12	17	12	17
C15	AKAMU NGWA	UG05	32	18	6

Table 2.4: Transportation Cost Matrix from Collection Centres (j) to Landfills (k)

		K	L1	L2	L3
J	Collection Centres	Notation	Umuhu Alaoji (Ob07)	Okpuala Aro (Os06)	Ngwaiyiekwe (Ug10)
C01	Osusu	An05	1040	1600	1760
C02	Uratta	An10	800	1280	1120
C03	Btc	An16	1200	1040	1840
C04	Asa Okpulor	An25	720	880	1280
C05	Eziukwu Asa Okpuaga	As03	1440	1840	1280

C06	Enyimba-Abaukwu	As07	1040	1360	800
C07	Igwebuike Nnentu	As15	1360	1600	1520
C08	Ehi Road	As21	1600	1280	1120
C09	Abayi	Ob01	640	1840	2160
C10	Umuagba	Ob05	400	2160	1920
C11	Ovom	Ob13	1120	1600	1280
C12	Abayi Ariaria	Os02	1520	640	880
C13	Umuojima Ogbu	Os03	1120	560	1120
C14	Umuaba	0s12	1360	960	1360
C15	Akamu Ngwa	Ug05	2560	1440	480

III. RESULTS AND ANALYSIS

The developed model was solved using MATLAB 2015a version. MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming. MATLAB is developed by MATHWORKS. It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces with programs written in other languages, including C, C++, Java and FORTRAN; analyze data; develop algorithms; and create models and applications. It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots, and performing numerical methods. In this section, the results and analysis of the developed model will be presented and discussed based on the following subheadings: Results, Sensitivity Analysis, Effect of Scavenged Fraction and Interpretation of Economic Concept

3.1 Economic Implications

The system of transporting waste from sources via collection centres to landfills must be beneficial to the investors, the waste generators (assumed as households in this study) and the government. This benefit is best guaranteed at the minimum cost of transportation network. The minima of transportation cost have been established in the foregoing through the procedure of integer programming. The clients are the generators and the revenue from the clients must cover the transportation cost, reasonable returns to the investors and reasonable tax returns to the government, for the investment to be considered viable. The importance of calculating the minimum cost is that the investment can be viable at the minimum cost with least charges on the generators.

Suppose a percentage p_1 of the minimum cost is supposed to be included as gross profit to the investor. The gross profit becomes

$$I_g = \frac{p_1}{100} C_{min} \quad (3.\ 1)$$

where C_{min} is the minimum cost from integer programming. Thus the cost to be charged by the investors becomes

$$C_{ch} = I_g + C_{min} = \left(\frac{p_1}{100} + 1\right) C_{min} \quad (3.2)$$

Suppose a percentage p_2 of the gross gain is to be paid as tax to the government, thus the total cost reads

$$C_{total} = \frac{p_1}{100}\frac{p_2}{100} C_{min} + \left(\frac{p_1}{100} + 1\right) C_{min} = \left(\frac{p_1 p_2}{10000} + \frac{p_1}{100} + 1\right) C_{min} \quad (3.3)$$

The profit to the investor becomes

$$G_i = C_{total} - C_{min} = \left(\frac{p_1 p_2}{10000} + \frac{p_1}{100}\right) C_{min}$$

The charge on each of the N households generating the waste becomes

$$P = \left(\frac{p_1 p_2}{10000} + \frac{p_1}{100} + 1\right) \frac{C_{min}}{N}$$

(3.4)

The developed model was solved using MATLAB 2015a version. MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming. MATLAB is developed by MathWorks. It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces with programs written in other languages, including C, C++, Java and FORTRAN; analyze data; develop algorithms; and create models and applications. It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots, and performing numerical methods

3.2 Sensitivity Analysis

3.2.1Effect of Capacity of Collection Centre

It was seen earlier that cost reduced monotonically with rise in capacity of the collection centre below C=322. The behavior at higher capacities is presented in Figure 3.1. It is seen that beyond C=322 there is a pattern of rise and fall in zigzag form, though on average, it can be concluded that minimal cost falls with rise in capacity of the collection centre.

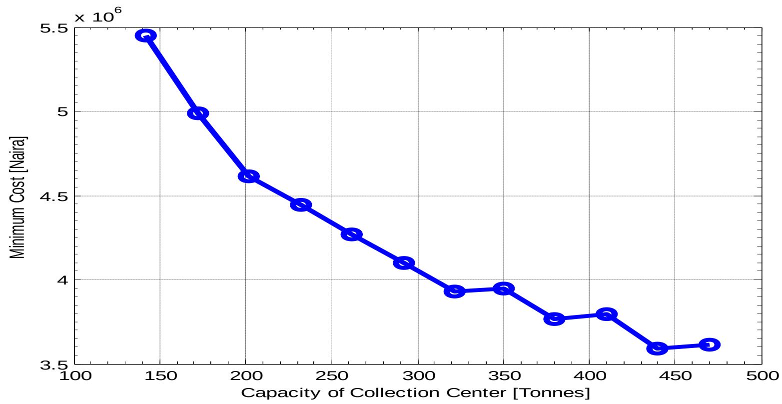

Figure 3.1: A Line Graph Plot of Minimal Costs against Capacities beyond Largest Practical Capacity of 350 tons

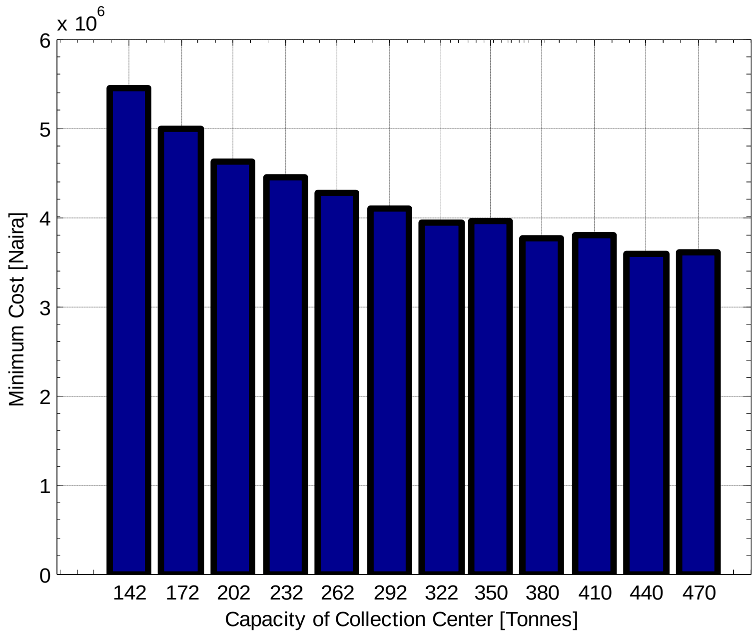

Figure 3.2: A bar Chat Plot of Minimal Costs against Capacities beyond Largest Practical Capacity of 350 tons

3.2.2 Effect of Hazard Cost

The other question to be addressed is the effect and sensitivity of minimal cost to change in cost of hazard. The parameters of the transportation network are same as in section 3.2.1**,** except that hazard cost of 1 ton of waste at collection is changed to ₦336.4875. The system is re-analyzed as follows; When C=142, the minimum cost is ₦5,594,700 and all the collection centres are open. When C=172, the minimum cost is ₦5,138,000 and the two closed collection centres for minimum cost are the Eziukwu Asa Okpuaga (AS03) and Ovom (OB13). When the collection centres are designed to have capacities of C=202, the minimum cost becomes ₦4,766,100 and the four closed collection centres are the Osusu (AN05), Eziukwu Asa Okpuaga (AS03), Igwebuike-Nnentu (AS15) and Ovom (OB13). When the collection centres are designed to have capacities of C=232, the minimum cost becomes ₦4,599,700 and the five closed collection centres for minimum cost are the Osusu (AN05), BTC (AN16), Eziukwu Asa Okpuaga (AS03), Ehi Road (AS21) and Ovom (OB13). When the collection centres are designed to have capacities of C=262, the minimum cost becomes ₦4,430,300 and the six closed collection centres for minimum cost are the Osusu (AN05), Uratta (AN10), BTC (AN16), Eziukwu Asa Okpuaga (AS03), Ehi Road (AS21) and Ovom (OB13). When the collection centres are designed to have capacities of C=292, the minimum cost becomes ₦4,259,300 and the seven closed collection centres for minimum cost are the Osusu (AN05), Uratta (AN10), BTC (AN16), Eziukwu Asa Okpuaga (AS03), Ehi Road (AS21), Ovom (OB13) and Umuaba (OS12). When the collection centres are designed to have capacities of C=322, the minimum cost becomes ₦4,082,800 and the eight closed collection centres for minimum cost are the Osusu (AN05), Uratta (AN10), BTC (AN16), Eziukwu Asa Okpuaga (AS03), Ehi Road (AS21), Ovom (OB13), Umuaba (OS12) and Igwebuike-Nnentu (AS15). When the collection centres are designed to have the maximum capacities of C=350, the minimum cost becomes ₦4,114,900 and the eight closed collection centres for minimum cost are the Osusu (AN05), Uratta (AN10), BTC (AN16), Eziukwu Asa Okpuaga (AS03), Ehi Road (AS21), Ovom (OB13), Umuaba (OS12) and Igwebuike-Nnentu (AS15).

It is seen that the number and permutation of collection centres to be opened for minimal cost transportation network is independent of the hazard cost. Also the quantities of x_{ij} and y_{jk} at minimal cost is not affected by hazard cost. Only the minimal transportation cost is affected by cost of hazard and the results confirm the expectation that rise in hazard cost will cause a rise in minimal transportation cost. To further buttress this point, h=₦540 is also considered and the results are presented in Table 3.1 and plotted as minimal costs against capacities in Figure 3.3. It is seen that cost reduced monotonically with rise in capacity of the collection centre even at higher hazard costs. The downward zigzag behavior beyond C=322 is also not affected by rise in h.

Table3.1: Effect of Collection Centre Capacity, ***C*** and Hazard Cost, ***h*** on Minimal Transportation Cost

C	142	172	202	232	262	292	322	350
Cost when h = ₦268.65	5,450, 200	4,986,400	4,615,300	4,442,300	4,270,300	4,100,800	3,929,900	3,948,700
Cost when h = 336.49	5,594,700	5,138,000	4,766,100	4,599,700	4,430,300	4,259,300	4,082,800	4,114,900
Cost when h = 540	6,028,200	5,593,100	5,218,300	5,071,900	4,910,100	4,734,700	4,541,600	4,613,500

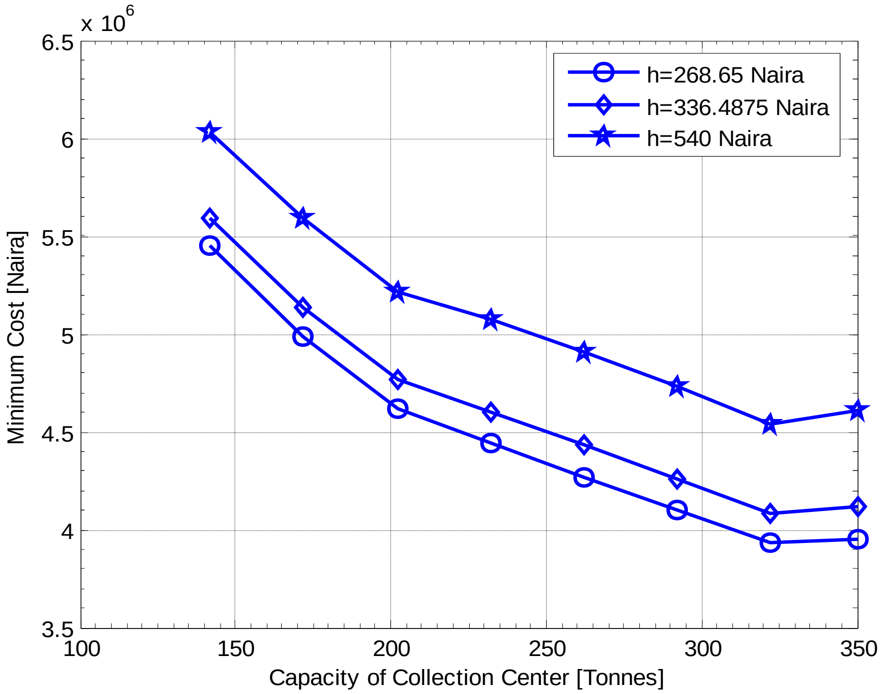

Figure 3.3: A Line Graph Plot of Minimal Costs against Collection Centre Capacities for Different Values of Hazard Cost to Show that Rise in Hazard Cost ***h*** Causes Rise in Cost

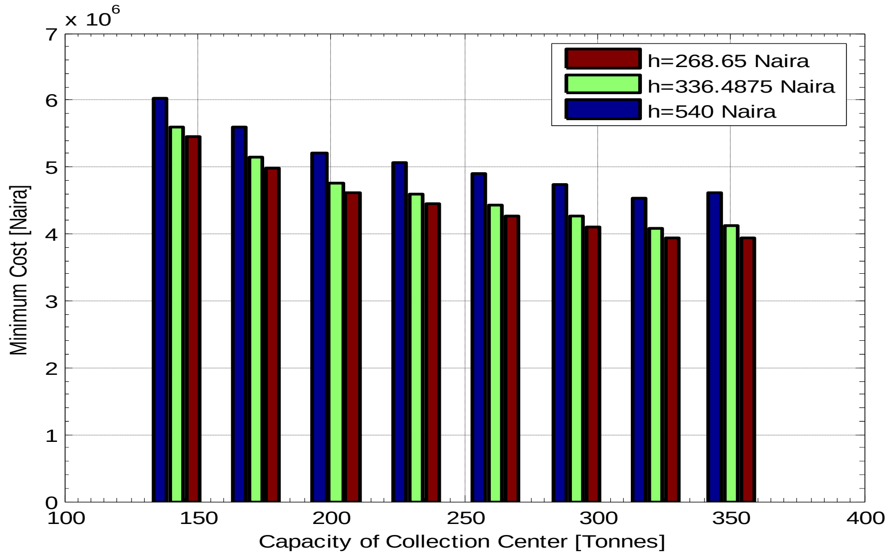

Figure 3.4: A Bar Chart Plot of Minimal Costs against Capacities for Different Values of Hazard Cost to Show that Rise in ***h*** Causes Rise in Cost.

3.2.3 Effect of Scavenged Fraction

The parameters of the transportation network are; number of collection centres 15, number of sources 90, number of landfills centers 3, fixed cost of collection centre ₦112,500.00 hazard cost of 1ton of waste at collection centre ₦268.65, scavenged fraction is varied from 0.119 to 0.6, total waste generated 2124 tons and number of collection centres to be stationed is 15. It is seen that the number and permutation of collection centres to be opened for minimal cost transportation network is independent of the scavenged fraction. Albeit, the quantities moved (x_{ij} and y_{jk}) at optimal and the minimal transportation cost is affected by scavenged fraction. These results confirm the expectation that rise in scavenged fraction will cause a fall in minimal transportation cost and the quantities moved to the landfills. The results are presented in Table 3.2 and plotted as minimal costs against scavenged fraction in Figure 3.5. It is seen that cost reduced monotonically with rise in scavenged fraction.

In order to illustrate how the quantities moved (x_{ij} and y_{jk}) at optimal is affected by scavenged fraction, the quantities moved from the Quantities moved from collection centreAsa Okpulor (AN25) to Umuhu Alaoji (landfill 1) are plotted as a function of scavenged fraction in Figure 3.6. Complete data on movement of quantities from collection centers to landfills is summarized in Table 3.2.

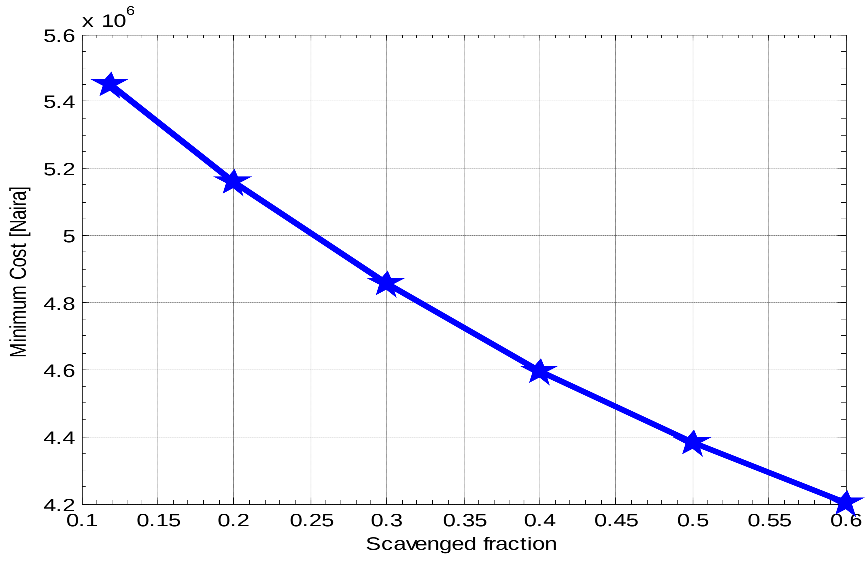

Figure 3.5: Minimum Transportation Cost versus Scavenged Fraction

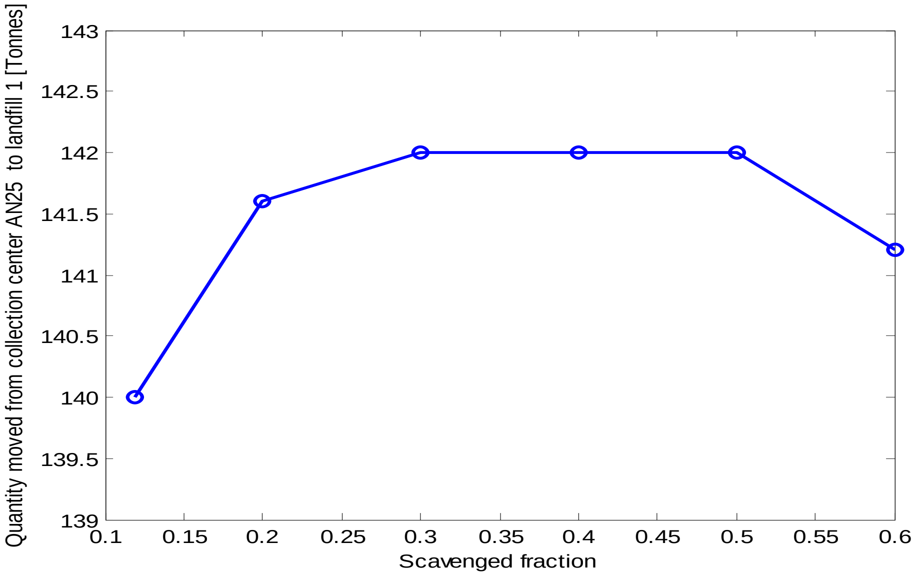

Figure 3.6: Quantity Moved From Collection Centre Asa Okpulor (AN25) to Umuhu Alaoji (Landfill 1)

Table 3.2: Results for Different Values of Scavenged Fraction when C=142 and h=268.65

F	0.119	0.2	0.3	0.4	0.5	0.6
Cost	5, 450, 200	5, 158, 500	4, 855, 100	4, 594, 700	4, 382, 800	4, 202, 800
Q_1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_{10}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_{11}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_{12}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_{13}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_{14}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Q_{15}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
C1-L1	142.0000	140.0000	140.0000	0	0	0
C1-L2	0	0	0	0	0	0
C1-L3	0	0	0	0	0	0
C2-L1	142.0000	142.0000	142.0000	142.00000	142.0000	0
C2-L2	0	0	0	0	0	0
C2-L3	0	0	0	0	0	0
C3-L1	0	0	0	0	0	0
C3-L2	142.0000	142.0000	71.0000	0	0	0
C3-L3	0	0	0	0	0	0
C4-L1	140.0000	141.6000	142.0000	142.0000	142.0000	141.2000
C4-L2	2.0000	0.4000	0	0	0	0
C4-L3	0	0	0	0	0	0
C5-L1	0	0	0	0	0	0
C5-L2	0	0	0	0	0	0
C5-L3	28.7680	0	0	0	0	0
C6-L1	0	0	0	0	0	0
C6-L2	0	0	0	0	0	0
C6-L3	142.0000	142.0000	142.00000	142.0000	70.0000	0
C7-L1	0	0	0	0	0	0
C7-L2	0	0	0	0	0	0
C7-L3	0	0	0	0	0	0
C8-L1	0	0	0	0	0	0
C8-L2	0	0	0	0	0	0
C8-L3	142.0000	142.0000	0	0	0	0
C9-L1	142.0000	142.0000	142.0000	142.0000	142.0000	142.0000

C9-L2	0	0	0	0	0	0
C9-L3	0	0	0	0	0	0
C10-L1	142.0000	142.0000	142.0000	142.0000	142.0000	142.0000
C10-L2	0	0	0	0	0	0
C10-L3	0	0	0	0	0	0
C11-L1	0	0	0	0	0	0
C11-L2	0	0	0	0	0	0
C11-L3	142.0000	0	0	0	0	0
C12-L1	0	0	0	0	0	0
C12-L2	142.0000	142.0000	142.0000	142.0000	142.0000	142.0000
C12-L3	0	0	0	0	0	0
C13-L1	0	0	0	0	0	0
C13-L2	142.0000	142.0000	142.0000	142.0000	142.0000	142.0000
C13-L3	0	0	0	0	0	0
C14-L1	0	0	0	0	0	0
C14-L2	142.0000	142.0000	142.0000	142.0000	0	0
C14-L3	0	0	0	0	0	0
C15-L1	0	0	0	0	0	0
C15-L2	0	0	0	0	0	0
C15-L3	142.0000	142.0000	142.0000	142.0000	142.0000	142.0000

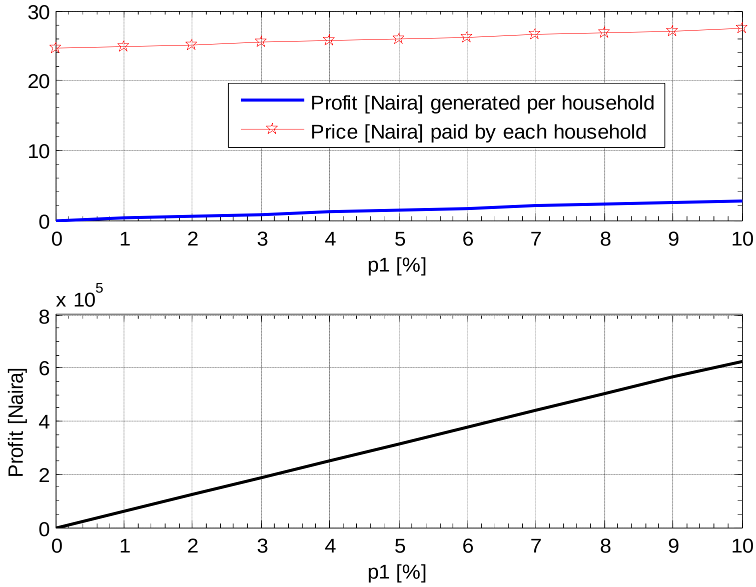

Figure 3.7: Economic Result When Capacity of each =14

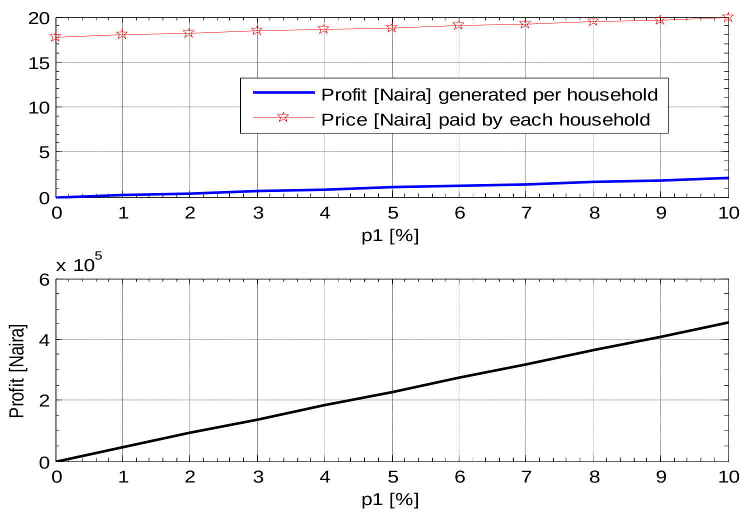

Figure 3.8: Economic Result when Capacity of each Center is 350

IV. SUMMARY, CONCLUSION AND RECOMMENDATION

In this work, we have been able to perform the economic analysis of the Municipal Solid Waste disposal in Aba metropolis of Abia State of Nigeria. The data collected were analyzed using Linear Programming toolbox of MATLAB 2015a software for Windows. But the solid waste management was modeled in Kalu, et al (2017) and there was need to conduct the economic analysis, hence, this work.

4.2 Conclusion

If P_1 is a percentage of the gross profit and P_2 is gain paid as tax to the Government, it is seen that even if P_1 can be as high as 10% that the daily cost on the households will still be less than ₦20. The daily profit generated will be enormous at ₦450000. When p_1 is as low as 3.2%, the daily profit will still be lucrative at ₦150000 and each household would need to make daily pay that is slightly less than ₦18.5 per day. It is seen that the best way to minimized the burden of payment on the customer while guaranteeing reasonable daily profit to the investor and tax return to the government is to increase the capacity of the collection centres and optimal place to locate them. When the effect of the capacity of the collection center was carried out it was observed that minimal cost falls with rise in capacity of the collection centre. It is seen that the number and permutation of collection centres to be opened for minimal cost transportation network is independent of the scavenged fraction, but the quantities moved x_{ij} and y_{jk} at optimal and the minimal transportation cost is affected by scavenged fraction. These results confirm the expectation that rise in scavenged fraction will cause a fall in minimal transportation cost and the quantities moved to the landfills, see Figure 3.6. The analysis further reveals that when the collection centers are designed to have the maximum capacities of C=350 with other things being equal, the minimum cost becomes ₦3,948,700.00 and 7 out of the 15 collection centres are open and thus in use. The eight closed collection centers for minimum cost are the Osusu (AN05), Uratta (AN10), BTC (AN16), Eziukwu Asa Okpuaga (AS03), Ehi Road (AS21), Ovom (OB13), Umuaba (OS12) and Igwebuike-Nnentu (AS15). The economic results becomes as shown in Figure 3.8.
Effect of hazard cost was analyzed and it was found that only the minimum transportation cost is affected by cost of hazard and the results confirm the expectation that rise in hazard cost will cause a rise in minimal transportation cost.

4.3Recommendations

In order to ensure the adoption and practice of the MSWMS model in Aba, there is the need to recognize the contribution of the private informal sectors such as scavengers and itinerant waste buyers in urban solid waste management. The private informal sector needs to be organized into associations and groups so that programs can be designed to build their capacities and also assist them with protective equipment to efficiently participate in the solid waste management process. Through the formation of co-operative societies or micro-enterprises, it is often possible to considerably increase the job stability and earnings of such informal sector workers and to enhance the effectiveness of their contribution to waste management. In order to improve solid waste management in Aba, the municipal authority and private companies need to formulate strategies and implement technological innovations necessary for effecting improved separation at source, resource recovery, recycling and disposal of solid waste in Aba. Some of the known technologies observed in Indian cities such as incineration, conversion to bio-gas, refuse derived fuel and composting can as well be adopted and practiced in Aba.

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