OPTIMAL EDC BILL-MIX THROUGH PARAMETERS TUNING IN AN OPTIMIZATION MODEL

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ABSTRACT*: There has been the problem of inappropriate billing of customers by Electricity Distribution Companies (EDCs) in Nigeria. We considered an explicit minimization constrained optimization model where the objective and constraint functions are all linear, for a scenario involving bills (EDCs) generate for their customers. Our model optimizes the bills for different household types. To get a bill-mix that is optimal in the view of customers, model parameters are tuned to fit in with field data collected by the companies. The model was implemented using the computer software,* ***Solver,*** *and the results are presented.*

KEYWORDS: optimization, solver, parameter tuning, customers, bill, model, EDC

INTRODUCTION

Viewing optimization as a collection of mathematical principles and methods used for solving quantitative problems that proffer solutions in diverse disciplines, including physics, biology, engineering, economics, and business as quantitative problems in these different disciplines have important mathematical elements in common and because of this commonality, many problems can be formulated and solved by using the unified set of ideas and methods that make up the field of optimization (Wright, 2021). The current trend in optimization is that any solution approach that seeks to maximize or minimize a given entity is an optimization process irrespective of the domain. For instance, Floudas et al. (2013) applied optimization to the problem of climate change; Gunantara (2018) applied multi-objective optimization (MOO) in the field of politics; Marchuk (1976) investigated the environment and problems of optimizing the distribution of industrial enterprises; Ojarikre (2018) compared block-structured linear programming (LP) models against other practical optimization methods for solving downstream refinery problems using a solution method different from the existing ones; Soroush et al. (2009) studied a static single machine scheduling problem in which processing times, due-dates, and penalties for not completing jobs on time are distinct arbitrary random variables and where the

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objective was to identify an optimal sequence, which minimizes the expected weighted sum of a quadratic function of job lateness.

The Problem

There has been the issue of inappropriate billings of EDCs customers in Nigeria by these companies. According to Emeka (2010), the current customer classification is too large for ease of understanding by officials of the EDCs. This statement by an official of Nigerian Electricity Regulatory Commission (NERC) shows that no scientific approach is being used by electricity providers and distributors in Nigeria with respect to billing. This necessitated the paper.

The Solution

We developed a model that optimizes the bills for different household types. To achieve optimal bill-mix for different household types, appropriate parameters of the model are tuned. In our model, the parameters include bills generated by the EDCs for electricity consumption per month for each household type, and the quantity of electricity consumed by each electrical appliance.

Model Formulation

Compactly and implicitly, we are looking at the model of the form:

Minimizing $f_o(x)$
Subject to $f_i(x) \geq b_i;\ i = 1, \ldots, m$

where $f_o(x)$ *is the objection function and the* $f_i(x)$ *are the constraints.*

In the less compact form, we have:

$$\begin{array}{ll} \text{Minimize} & c_1x_1 + \ldots + c_nx_n \\ \text{Subject to} & a_{11}x_1 + \ldots + a_{1n}x_n \geq b_1 \\ & \ldots \quad \ldots \quad \ldots \quad \ldots \\ & a_{m1}x_1 + \ldots + a_{mn}x_n \geq b_m \end{array}$$
$$x_1, \ldots, x_n \geq 0$$

Where:

The c_j's are the bill generated by an EDC for each household type per month, $j = 1, \ldots, 6$.

The x_j's are the number of each household type, $j = 1, \ldots, 6$.

The a_{ij}'s are the kWh consumed by each electrical appliance for each household; type, $i = 1, \ldots, 19$, $j = 1, \ldots, 6$.

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Model Decision Variables

We considered six household types as follows:
the number of one-room apartments $=x_1$
the number of bed-sitter apartments $=x_2$
the number of room-and-parlour apartment $= x_3$
the number of self-contained apartments $= x_4$
the number of two-bed-room apartments $= x_5$
the number of three-bed-room apartments $= x_6$

Model Constraints

We considered nineteen household electrical appliances and the restrictions imposed on them are the constraints.

Table 1: The number of each appliance owned by one unit of each apartment type.

	1-Room	Bed-Sitter	Room & Parlour	Self-Contained	2-Bed-Room	3-Bed-Room
Fan (x_1)	1	1	2	3	4	5
LED Light Bulb (x_2)	3	4	10	10	14	17
AC (x_3)	0	1	0	1	3	4
Refrigerator (x_4)	1	1	1	1	2	2
Electric Heater (x_5)	1	1	1	1	1	1
Water Heater (x_6)	1	1	1	1	1	1
Hair Dryer (x_7)	0	0	0	1	1	1
Clothes Dryer (x_8)	0	0	0	1	1	1
Clothes Iron (x_9)	1	1	1	1	1	1
Dishwasher (x_{10})	0	0	0	0	1	1
Electric Kettle (x_{11})	1	1	1	1	1	1
Toaster Oven (x_{12})	0	0	0	1	1	1
Microwave Oven (x_{13})	0	0	0	1	1	1
Desktop Computer (x_{14})	1	1	1	1	1	1
Laptop Computer (x_{15})	1	1	1	2	2	2
TV (x_{16})	1	1	1	1	2	2
Stereo Receiver (x_{17})	1	1	1	1	1	1
Vacuum Cleaner (x_{18})	0	0	0	0	1	1
Washing Machine (x_{19})	0	0	0	0	1	1

The monthly EDC bill (generated) for each household type in Nigeria is N700, N1,000; N1,500; N2,000, N3,000; and N4,500 for household type 1, 2, 3, 4, 5, and 6 respectively. Given that household electricity consumption works out at between 8 and 10 hours per day (thus averaging 9 hours per day in Nigeria) and according Massiha (2002), to calculate the kWh for a specific appliance, multiply the power rating (watts) of the appliance by the amount of time (hrs) you use the appliance and divide by 1000; Table 2 presents the watts rate for each appliance, along with

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kilo watts hour (kWh) consumed by each apartment type on each appliance, and the total minimum kWh available for each appliances per month.

Table 2: kWh = (watts rate X hr of usage)/1000

	1-Room (N700)	Bed-Sitter (N1,000)	Room & Parlour (N1,500)	Self-Contained (N2,000)	2-Bed-Room (N3,000)	3-Bed-Room (N4,500)	(9 hours/day X 30 days)
Fan (x_1) 80 watts	.08x_1	0.08x_2	0.16x_3	.24x_4	0.32x_5	0.4x_6	345 kWh
LED Light Bulb (x_2) 25 watts	.075 x_1	0.10 x_2	0.25 x_3	0.25 x_4	.35 x_5	.425 x_6	391 kWh
AC (x_3) 900 watts	0	0	0	0.9 x_4	2.7 x_5	3.6 x_6	1944 kWh
Refrigerator (x_4) 250	0.25 x_1	0.25 x_2	0.25 x_3	0.25 x_4	0.5 x_5	0.5 x_6	540 kWh
Electric Heater (x_5) 2000 watts	2 x_1	2 x_2	2 x_3	2 x_4	2 x_5	2 x_6	(1 hour/day) X 30 days: 360
Water Heater (x_6) 4000 watts	0	0	0	4 x_4	8 x_5	12 x_6	(4.5 hours/day) X 30 days: 3240 kWh
Hair Dryer (x_7) 1500	0	0	0	1.5 x_4	1.5 x_5	1.5 x_6	1215 kWh
Clothes Dryer (x_8) 3000 watts	0	0	0	3 x_4	3 x_5	3 x_6	(1 hour/day) X 30 days: 270 kWh
Clothes Iron (x_9) 1400 watts	1.4 x_1	1.4 x_2	1.4 x_3	1.4 x_4	1.4 x_5	1.4 x_6	(1 hour/day) X 30 days: 252 kWh
Dishwasher (x_{10}) 1300 watts	0	0	0	0	1.3 x_5	1.3 x_6	(1 hour/day) X 30 days: 108 kWh
Electric Kettle (x_{11}) 1700 watts	1.7 x_1	1.7 x_2	1.7 x_3	1.7 x_4	1.7 x_5	1.7 x_6	(1 hour/day) X 30 days: 306 kWh
Toaster Oven (x_{12}) 1100 watts	0	0	0	1.1 x_4	1.1 x_5	1.1 x_6	(1 hour/day) X 30 days: 99 kWh
Microwave Oven (x_{13}) 1000 watts	0	0	0	1 x_4	1 x_5	1 x_6	(1 hour/day) X 30 days: 90 kWh
Desktop Computer (x_{14}) 150 watts	0.15 x_1	0.15 x_2	0.15 x_3	0.15 x_4	0.15 x_5	0.15 x_6	(4.5 hour/day) X 30 days: 121 kWh
Laptop Computer (x_{15}) 100 watts	0.1 x_1	0.1 x_2	0.1 x_3	0.2 x_4	0.2 x_5	0.2 x_6	(4.5 hour/day) X 30 days: 121 kWh
TV (x_{16}) 120	0.12 x_1	0.12 x_2	0.12 x_3	0.12 x_4	0.24 x_5	0.24 x_6	259 kWh
Stereo Receiver (x_{17}) 300 watts	0.3	0.3	0.3 x_3	0.3 x_4	0.3 x_5	0.3 x_6	486 kWh
Vacuum Cleaner (x_{18}) 1200 watts	0	0	0	0	1.2 x_5	1.2 x_6	(1 hour/day) X 30 days: 72 kWh
Washing Machine (x_{19}) 1500 watts	0	0	0	0	1.5 x_5	1.5 x_6	(1 hour/day) X 30 days: 90 kWh

The Proposed Model

Given the information contained in Table 1 and Table 2, implicit form of the model:

Minimize $\quad c_1x_1 + \dots + c_nx_n$

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Subject to $a_{11}x_1 + \ldots + a_{1n}x_n \geq b_1$

$\ldots \quad \ldots \quad \ldots \quad \ldots$

$a_{m1}x_1 + \ldots + a_{mn}x_n \geq b_m$

$x_1, \ldots, x_n \geq 0$; $n = 6$, $m = 19$

becomes explicit as:

$$
\begin{aligned}
&\text{Optimize Cost} = 700x_1 + 1000x_2 + 1500x_3 + 2000x_4 + 3000x_5 + 4500x_6 \\
&\text{Subject to} \\
&0.080x_1 + 0.080x_2 + 0.160x_3 + 0.240x_4 + 0.320x_5 + 0.400x_6 \geq 345 \\
&0.075x_1\ 0.100x_2 + 0.250x_3 + 0.240x_4 + 0.350x_5 + 0.425x_6 \geq 391 \\
&0.900x_4 + 2.700x_5 + 3.600x_6 \geq 1944 \\
&0.250x_1 + 0.250x_2 + 0.250x_3 + 0.250x_4 + 0.500x_5 + 0.500x_6 \geq 540 \\
&2.000x_1 + 2.000x_2 + 2.000x_3 + 2.000x_4 + 2.000x_5 + 2.000x_6 \geq 360 \\
&4.000x_4 + 8.000x_5 + 12.00x_6 \geq 3240 \\
&1.500x_4 + 1.500x_5 + 1.500x_6 \geq 1215 \\
&3.000x_4 + 3.000x_5 + 3.000x_6 \geq 270 \\
&1.400x_1 + 1.400x_2 + 1.400x_3 + 1.400x_4 + 1.400x_5 + 1.400x_6 \geq 252 \\
&1.300x_5 + 1.300x_6 \geq 108 \\
&1.700x_1 + 1.700x_2 + 1.700x_3 + 1.700x_4 + 1.700x_5 + 1.700x_6 \geq 306 \\
&1.100x_4 + 1.100x_5 + 1.100x_6 \geq 99 \\
&1.000x_4 + 1.000x_5 + 1.000x_6 \geq 90 \\
&0.150x_1 + 0.150x_2 + 0.150x_3 + 0.150x_4 + 0.150x_5 + 0.150x_6 \geq 121 \\
&0.100x_1 + 0.100x_2 + 0.100x_3 + 0.200x_4 + 0.200x_5 + 0.200x_6 \geq 121 \\
&0.120x_1 + 0.120x_2 + 0.120x_3 + 0.120x_4 + 0.240x_5 + 0.240x_6 \geq 259 \\
&0.300x_1 + 0.300x_2 + 0.300x_3 + 0.300x_4 + 0.300x_5 + 0.300x_6 \geq 486 \\
&0.120x_5 + 0.120x_6 \geq 72 \\
&0.150x_5 + 0b.150x_6 \geq 90 \\
&x_1, x_2, x_3, x_4, x_5, x_6 \geq 0
\end{aligned}
$$

Implementation of Model

The above model was implemented using the computer software (Microsoft Excel LPP *Solver*).

RESULTS

The extracted results are presented below:

Answer Report

Worksheet: [Optimize Cost.xlsx]Sheet2
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Target Cell (Min)

Cell	Name	Original Value	Final Value
$B$5	Cost	0	3159114.754

Adjustable Cells

Cell	Name	Original Value	Final Value
$B$9	Number of One-Room Apartments (x1)	0	438.6065574
$B$10	Number of Bed-Sitter Apartments (x2)	0	0
$B$11	Number of Room and Parlour Apartments (x3)	0	319.1803279
$B$12	Number of Self-Contained Apartments (x4)	0	213.3196721
$B$13	Number of Two-Bed-Room Apartments (x5)	0	648.8934426
$B$14	Number of Three-Bed-Room Apartments (x6)	0	2.08898E-14

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$18	fans constraint	345	$B$18>=$C$18	Binding	0
$B$19	LED light bulbs constraint	391	$B$19>=$C$19	Binding	0
$B$20	AC - air conditioners constraint	1944	$B$20>=$C$20	Binding	0
$B$21	refrigerators constraint	567.2233607	$B$21>=$C$21	Not Binding	27.22336066
$B$22	electric heaters constraint	3240	$B$22>=$C$22	Not Binding	2880
$B$23	water heaters constraint	6044.42623	$B$23>=$C$23	Not Binding	2804.42623
$B$24	hair dryers constraint	1293.319672	$B$24>=$C$24	Not Binding	78.31967213
$B$25	clothes dryers constraint	2586.639344	$B$25>=$C$25	Not Binding	2316.639344

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$B$26	**clothes iron constraint**	**2268**	**$B$26>=$C$26**	**Not Binding**	**2016**
$B$27	**dishwashers constraint**	**843.5614754**	**$B$27>=$C$27**	**Not Binding**	**735.5614754**
$B$28	**electric kettles constraint**	**2754**	**$B$28>=$C$28**	**Not Binding**	**2448**
$B$29	**toaster ovens constraint**	**948.4344262**	**$B$29>=$C$29**	**Not Binding**	**849.4344262**
$B$30	**microwave oven constraint**	**862.2131148**	**$B$30>=$C$30**	**Not Binding**	**772.2131148**
$B$31	**desktop computers constraint**	**243**	**$B$31>=$C$31**	**Not Binding**	**122**
$B$32	**laptop computers constraint**	**248.2213115**	**$B$32>=$C$32**	**Not Binding**	**127.2213115**
$B$33	**TV - television sets constraint**	**272.2672131**	**$B$33>=$C$33**	**Not Binding**	**13.26721311**
$B$34	**stereo receivers constraint**	**486**	**$B$34>=$C$34**	**Binding**	**0**
$B$35	**vacuum cleaners constraint**	**77.86721311**	**$B$35>=$C$35**	**Not Binding**	**5.867213115**
$B$36	**washing machines constraint**	**97.33401639**	**$B$36>=$C$36**	**Not Binding**	**7.334016393**
$B$37	**x1 non-negativity constraint**	**438.6065574**	**$B$37>=$C$37**	**Not Binding**	**438.6065574**
$B$38	**x2 non-negativity constraint**	**0**	**$B$38>=$C$38**	**Binding**	**0**
$B$39	**x3 non-negativity constraint**	**319.1803279**	**$B$39>=$C$39**	**Not Binding**	**319.1803279**
$B$40	**x4 non-negativity constraint**	**213.3196721**	**$B$40>=$C$40**	**Not Binding**	**213.3196721**
$B$41	**x5 non-negativity constraint**	**648.8934426**	**$B$41>=$C$41**	**Not Binding**	**648.8934426**
$B$42	**x6 non-negativity constraint**	**2.08898E-14**	**$B$42>=$C$42**	**Binding**	**0**

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Sensitivity Report

Worksheet: [Optimize Cost.xlsx]Sheet2

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Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$9	Number of One-Room Apartments (x1)	438.6065574	0	700	255.3571429	97.05882353
$B$10	Number of Bed-Sitter Apartments (x2)	0	0	1000	1E+30	234.4262295
$B$11	Number of Room and Parlour Apartments (x3)	319.1803279	0	1500	472.7272727	266.6666667
$B$12	Number of Self-Contained Apartments (x4)	213.3196721	0	2000	165	198.0952381
$B$13	Number of Two-Bed-Room Apartments (x5)	648.8934426	0	3000	594.2857143	305.4054054
$B$14	Number of Three-Bed-Room Apartments (x6)	2.08898E-14	0	4500	1E+30	777.0491803

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$B$18	fans constraint	345	4262.295082	345	6.817142857	3.64
$B$19	LED light bulbs constraint	391	2622.95082	391	7.9625	14.9125
$B$20	AC - air conditioners constraint	1944	205.8287796	1944	220.5	72.5472973
$B$21	refrigerators constraint	567.2233607	0	540	27.22336066	1E+30
$B$22	electric heaters constraint	3240	0	360	2880	1E+30
$B$23	water heaters constraint	6044.42623	0	3240	2804.42623	1E+30
$B$24	hair dryers constraint	1293.319672	0	1215	78.31967213	1E+30
$B$25	clothes dryers constraint	2586.639344	0	270	2316.639344	1E+30
$B$26	clothes iron constraint	2268	0	252	2016	1E+30
$B$27	dishwashers constraint	843.5614754	0	108	735.5614754	1E+30
$B$28	electric kettles constraint	2754	0	306	2448	1E+30
$B$29	toaster ovens constraint	948.4344262	0	99	849.4344262	1E+30
$B$30	microwave oven constraint	862.2131148	0	90	772.2131148	1E+30
$B$31	desktop computers constraint	243	0	121	122	1E+30
$B$32	laptop computers constraint	248.2213115	0	121	127.2213115	1E+30
$B$33	TV - television sets constraint	272.2672131	0	259	13.26721311	1E+30
$B$34	stereo receivers constraint	486	540.9836066	486	23.8875	24.60185185

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$B$35	vacuum cleaners constraint	77.86721311	0	72	5.867213115	1E+30
$B$36	washing machines constraint	97.33401639	0	90	7.334016393	1E+30
$B$37	x1 non-negativity constraint	438.6065574	0	0	438.6065574	1E+30
$B$38	x2 non-negativity constraint	0	234.4262295	0	477.7678571	318.5
$B$39	x3 non-negativity constraint	319.1803279	0	0	319.1803279	1E+30
$B$40	x4 non-negativity constraint	213.3196721	0	0	213.3196721	1E+30
$B$41	x5 non-negativity constraint	648.8934426	0	0	648.8934426	1E+30
$B$42	x6 non-negativity constraint	2.08898E-14	777.0491803	0	117.962963	1573.823529

Interpretation of Results and Discussion

Extracting the results show that given the bills generated for the different household types, there should be in the locality:

438 One-Room apartments
319 Room & Parlour apartments
213 Self-Contained apartments
648 Two-Bed Room apartments
2 Three-Bed Room apartments and
no Bed-Sitter apartments.

Parameters Tuning

If the above distribution aligns with field data collected by an EDC, there would be no complaints by the customers, but if not, the c_j's are tuned until the result got from the model converges to field data (which are the actual numbers of these household types in the locality) and the c_j's got from that tuning is the optimal bill-mix.

The constraints for fans, LED light bulbs, AC air conditioners, and stereo receivers are binding, while those for all other appliances are not binding. For this results, the total cost is N3,159,114.754 for the locality.

CONCLUSION

This work, if implemented will be able to solve the age-long problem of inappropriate billing of customers by Electricity Distribution Companies (EDCs) in Nigeria through parameters tuning of the model parameters such that results got from the model converge to field data. The EDCs would need to demarcate all the areas they serve into defined units of clusters of appropriate distributions of the different house-hold types.

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