Simplex Optimization of Production Mix: A Case of Custard Producing Industries in Nigeria

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Abstract

The study used two custard producing industries, LCI and KFGI as case studies in which time study of their various kinds of labour in custard production as well as the associated sizes of custard and costs were analysed. With the obtained results, a mathematical model was set up using simplex method in which the problem was converted into its standard form of linear programming problem. Simplex method of optimization was used in determining the optimal production proportion and profit margins. The case study of LCI results gave an optimal production mix of 45.8%, 39.6% and 14.6% for large, medium and small sized custard, respectively, with an increase in profit margin to 49.8% translating into ₦728,142:00 for the month of March, 2013. Similarly, KGFI have an optimal production mix of 43.5%, 36.5% and 20% for large, medium and small sized custard with an increase in profit margin to 51.5% translating into ₦ 905,423.00 for the month of August, 2013.

Keywords: Custard Production, Simplex Optimization, Optimal Mix, Simulation

Introduction

Custard powder is a popular dessert item and is often served with egg pudding and jelly crystals. With increasing disposable incomes and changing life-styles, eating habits have also witnessed a definite shift. This phenomenon is no more restricted to the urban elites but it is spreading very fast to other areas as well. Thus, the contemplated products have experienced continuous increase in demand during last few years. Consistent advertising by some established manufacturers have made these products very popular which would help the new entrants provided the product quality is comparable and prices are competitive. Custard industry in Nigeria is one of the fastest food related growing industries in the country. Worthy of note is the fact that most of these industries are faced with the problem of optimizing production cost and the corresponding quantity of the product to meet with the customers demand. They are concerned with the rate of productivity which can be related to the efficiency of the production system. It could equally be seen as a ratio to measure how well an organization (or individual, industry, country) converts input resources (labour, materials, machines, etc.) into goods and services.

Even though there is increase in demand, consumers have become more and more demanding, and the key to firm survival is the recognition of the importance of customer satisfaction. Consequently, companies have been forced to enhance the quality of both their processes and products (Efstratiadis et al., 2000). The focus of this study, the food industry, has also become increasingly multifaceted and competitive in recent years (Chong et al., 2001; Knowles et al., 2004; Spiegel et al., 2006). In this environment, company managers have to deal with a number of problems. Sales are slowing down and operating costs are increasing, while customers are becoming more demanding and selective (Henchion and McIntyre, 2005). Considering the above, this study intends to carry out simplex optimization with a view to determining the optimal production mix for custard producing industries.

In an optimization process, one usually begins with a real life problem, full of details and complexities, some relevant and some not. From this, essential elements are extracted and an algorithm or solution technique to apply to it. In practical problems, the computer will carry out the necessary calculations.

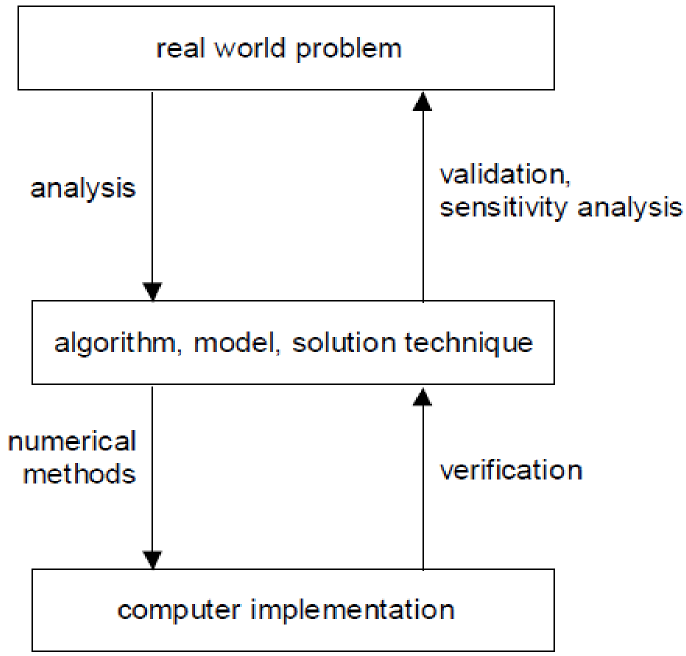


Fig 1: Optimization Process

Chinneck (2000) observes that there is an unavoidable loss of realism as one moves down the diagram in Fig 1 from *real world problem* to *algorithm, model, or solution technique*, and finally to *computer implementation*. After computer implementation, verification takes place. Verification refers to the process of confirming that the simulation model is correctly translated into a computer programme (Okonkwo, 2009). The process of testing and improving a model to increase its validity is commonly referred to as validation (Harvey, 1989). Hence, validation was done to ensure that the model is a true representation to what is obtainable in the real system. Similarly, sensitivity analysis is used to determine how sensitive the model parameters can be when varied, respectively.

Now coming to linear programming model of optimization, Dibua (2004) explained that linear programming model is best applied where a manufacturer wants to develop a production schedule/target and an inventory policy that will satisfy sales demand in future period. Ideally, the schedule and policy will enable the production company to satisfy demand and at the same time minimize the total production and inventory costs". Sonder (2005) observed that linear programming works by searching for the basic feasible solution and ends with the search of optimum solution. This goes to explain simplex method in a more understandable manner. Similarly, Martand (2003) submitted that linear programming could be used to solve the task of production planning and control in production processes which can be seen as highly complex in manufacturing environments while Everette (2003) said that linear programming could be used to provide uninterrupted production by optimizing production processes for efficiency.

Dantzig (1963) formulated a model which satisfactorily represented the technological relations usually encountered in practice. He decided that the ad hoc ground rules had to be discarded and replaced by an explicit objective function. He formulated the planning problem in mathematical terms using a set of axioms. The axioms concerned the relations between two kinds of sets: the first was the set of items being produced or consumed and the second, the set of activities or production processes in which these items would be inputted or outputted in fixed proportions provided these proportions are non-negative multiples of each other. Having seen that the model developed by George B. Dantzig is practically feasible, especially in production outfit such as custard, bread, paint industries, hence the adoption of the model for this study because simplex method technique rests on two concepts viz feasibility and optimality (start with the basic feasible solution or programme and goes ahead to search for optimum solution) and in graphical methods we search only the extreme point solutions. The solution is tested for optimality and if it is optimum, the search is stopped and if the test shows that it is not optimum, a new and better feasible solution is designed and that is guaranteed by the mechanics of the simplex or iterative method because each successive solution is designed only if it is better than each of the previous solutions. Repetition goes on until optimum solution is obtained.

Steps for Simplex Optimization

To apply the simplex/iterative method, it is necessary to state the problems in the form in which the inequalities in the constraints have been converted to equalities because it is not possible to perform arithmetic calculations upon an inequality. The inequalities in maximization problems are converted to equalities with the aid of slack variables to the left hand side of each inequality. The slack variables in maximizing problems represent any unused capacity in the constraint and its value can take from zero to the maximum of that constraint. Each constraint has its own separate slack variable. The inequalities in the minimization problems are converted into equalities by subtracting one surplus variable.

The simplex method for linear programming model follows the under listed steps:

i) Design the sample problem.
ii) Setup the inequalities describing the problem
iii) Convert the inequalities to equations adding slack variables.
iv) Enter the inequalities in a table for initial basic feasible solutions with all slack variables as basic variables. The table is called simplex table.
v) Compute C_j and P_j values for this solution where C_j is objective function coefficient for variable j and P_j represents the decrease in the value of the objective function that will result if one unit of variable corresponding to the column is brought into the solution.
vi) Determine the entering variable (key column) by choosing the one with the highest C_j-P_j value.
vii) Determine the key row (outgoing variable) by dividing the solution quantity values by their corresponding solution quantity values by their corresponding key column values and choosing the smallest positive quotient. This means that we compute the ratios for rows where elements in the key column are greater than zero.
viii) Identify the pivot element and compute the values of the key row by dividing all the numbers in the key row by the pivot element. Then change the product mix to the heading of the key column.
ix) Compute the values of the other non-key rows
x) Compute the P_j and C_j-P_j values for this solution.
xi) If the column value in the C_j –P_j row is positive, return to step (vi).

If there is no positive C_j-P_j, then the final solution has been reached

Linear Programming Model for the Case Studies

Max. P $= \sum_{j=i}^{n} C_j X_j$ (1)

Subject to the linear constraints

$\sum_{j=i}^{n} ai_j X_j \leq T_i$; i = 1, 2, ….., m
And $X_j \geq 0$; j = 1,2, ……………n

Equation 1 can be stated in generalized form with n decision variables and m constraints as follows in this form:
Max. P = $ax_1 + bx_2 + cx_3$ (2)

$$dx_1 + ex_2 + fx_3 \leq T_1$$
$$gx_1 + hx_2 + ix_3 \leq T_2$$
$$jx_1 + kx_2 + lx_3 \leq T_3$$
$$mx_1 + nx_2 + px_3 \leq T_4$$
$$qx_1 + rx_2 + sx_3 \leq T_5$$
$$ux_1 + vx_2 + wx_3 \leq T_6$$
$$(x_1, x_2, x_3 \geq 0)$$

Where: x_1, x_2, x_3 are the non-basic variables; and T_1, T_2, T_3, T_4, T_5, T_6 are the total available time.

To solve the mathematical set up model shown above using the simplex method, it requires that the problem be converted into its standard form of linear programing problem:

i. All constraints should be expressed as equations by adding slack variables or surplus variables.
ii. The right-hand side of each constraint should be made non-negative if it is not already. This should be done by multiplying both sides of the resulting constraints by -1.

iii. The objective function should be of the maximization type.

Equation (1) can be expressed as;

Max P = $\sum_{j=i}^{n} C_j X_j + \sum_{j=i}^{m} OS_j$ (3)

Subject to the constraints

$\sum_{j=i}^{n} ai_j X_j + S_i = T_i$; i = 1, 2, ... m

And X_j, Si, ≥ 0, for all i and j

Equation (3) can be expressed as;

Thus; Max. P = $ax_1 + bx_2 + cx_3 + OS_1 + OS_2 + OS_3 + OS_4 + OS_5 + OS_6$

Subject to the constraints;

$$dx_1 + ex_2 + fx_3 + S_1 + OS_2 + OS_3 + OS_4 + OS_5 + OS_6 = T_1$$
$$gx_1 + hx_2 + ix_3 + OS_1 + S_2 + OS_3 + OS_4 + OS_5 + OS_6 = T_2$$
$$jx_1 + kx_2 + lx_3 + OS_1 + OS_2 + S_3 + OS_4 + OS_5 + OS_6 = T_3$$
$$mx_1 + nx_2 + px_3 + OS_1 + OS_2 + OS_3 + S_4 + OS_5 + OS_6 = T_4$$
$$qx_1 + rx_2 + sx_3 + OS_1 + OS_2 + OS_3 + S_4 + OS_5 + OS_6 = T_5$$
$$ux_1 + vx_2 + wx_3 + OS_1 + OS_2 + OS_3 + S_4 + OS_5 + OS_6 = T_6$$
$$x_1, x_2, x_3, S_1, S_2, S_3, S_4 S_5, S_6 \geq 0 \text{ [non-negative]}$$

where

x_1, x_2 and x_3 are quantities of the big custards, medium custards and small custards respectively called the non-basic variables.

S_1, S_2, S_3 and S_4 are the slack variables used to eliminate the inequalities generated in the objective function of the LP model set up.

P_j = Expected profit to be made after optimization called the total gross amount for outgoing profit.
$C_j - P_j$ = Net evaluation row for the objective function of the LP model called decision variable.
C_j = objective function coefficients
$T_1, T_2, T_3, T_4, T_5, T_6$ = Total available time constants
a, b, c, d, e, f, g, h, i, j, k, I, m n, p, q, r, s, u, v and w are the process available time constants.

Application of Simplex Optimization to the Case Studies

Both LCI and KGFI were used as case studies. The operations of the two case studies are quite similar. Hence, detailed explanations of how it was applied to LCI was done while only the essential results were shown in that of KGFI. The official working hours of the LCI factory staff is from 8 am to 5 pm, which is 9 hours. The production period for the batch was assumed to be carried out for 7 hours in a day, while the balance of 2 hours is used for break and down time periods. Also, it was assumed that there was no production after official working hours. The company produces three sizes of custard: the big size custard, the medium size custard and the small size custard. These three sizes of custard require six kinds of labour: premixing, mixing, weighing, sealing, packaging and bagging. The six kinds of labour for the production process do not start at the inception of production. At the first hour of production, some kinds of labour must be completed before others start. Subsequently, they will now begin to go on simultaneously.

After carrying out time study, the average labour time per day for each labour as observed from the factory is as shown in Table 1.

Table 1: Average Processing Time per Day for LCI

Labour	Average Processing Time (Minutes)		
	1st hour	6 remaining hours	Per day
Premixing	60	240	280
Mixing	40	220	260
Weighing	20	358	378
Sealing	17	359	376
Packaging	15	360	375
bagging	12	360	372

Similarly average labour time per week (consisting of 5 ordinary days and 1 Saturday) and per month is as shown in Table 2.

Table 2: Average Processing Time of each Labour Per Week

Labour	Average Processing Time per Week in Minutes	Average Processing Time per Month (Minutes)
Premixing	1600	6880
Mixing	1480	6360
Weighing	2148	9228
Sealing	2136	9176
Packaging	2130	9150
Bagging	2112	9072

The average time required for the production of each of the sizes of custard is as tabulated in Table 3.

Table 3: Average Processing Time of each Labour for each Size of Custard for LCI

Labour	Large Custard Average Time (Min)	Medium Custard Average Time (Min)	Small Custard Average Time (Min)
Premixing	0.3	0.2	0.1
Mixing	0.3	0.2	0.1
Weighing	3	3	3
Sealing	2	2	2
Packaging	2	2	2
Bagging	2	2	2

Table 4: Average Processing Time of each Labour for each Size of Custard for KGFI

Labour	Large Custard Average Time (Min)	Medium Custard Average Time (Min)	Small Custard Average Time (Min)
Premixing	0.3	0.2	0.1
Mixing	0.2	0.2	0.1
Weighing	2	2	2
Sealing	3	3	3
Packaging	2	2	2
Bagging	3	3	3

Cost of Different Custard Size and Demand

After cost study of the case studies, the costing of products indicated that LCI and KGFI sells and makes profit from the different sizes of custard as shown in Table 5

Table 5: Prices for Profit for Different Custard Sizes for LCI and KGFI

Custard Size	Selling Price (₦)		Profit (₦)	
	LCI	KGFI	LCI	KGFI
Big	550	530	100	80
Medium	400	380	70	60
Small	120	130	20	20

LCI and KGFI are faced with a problem of optimization on the quantity of the three sizes of custard to be produced in each production batch for efficient productivity as their present production is not enough to meet demand. Besides, the industry has low profit margin due to inadequate production mix of each size. Louis Carter Industry does not have problem with the selling of produced custard because there is high demand for their products. Hence, the need for a production mix that will enhance profit maximization and cost minimization with a view to meeting their customers demand.

The case study processing time of the various custard sizes, profit made and total available time were transformed into a frame work to enable simplex optimization.

Transforming Case Study Data and Performing Simplex Optimization

The process time per custard size, profit made and total available time for each of the available labour time of the two cast studies are shown in Table 7 and 8 for LCI and KGFI, respectively.

Table 7: Case Study, Processing Time, Profit and Total Available Time for LCI

Size of custards	Process Time (Min.) Per custard Size						Profit per custard
	Pre mixing	Mixing	Weighing	Sealing	Packaging	Bagging	
Large custard (x_1) Medium custard (x_2) small custard (x_3)	0.3 0.2 0.1	0.3 0.2 0.1	3 3 3	2 2 2	2 2 2	3 3 3	100 70 20
Total available Time (mins/day)	280	260	378	376	375	372	

Table 8: Case Study, Processing Time, Profit and Total Available Time for KGFI

Size of custards	Process Time (Min.) Per custard Size						Profit per custard
	Pre mixing	Mixing	Weighing	Sealing	Packaging	Bagging	
Large custard (x_1) Medium custard (x_2) small custard (x_3)	0.3 0.2 0.1	0.2 0.2 0.1	3 3 3	2 2 2	2 2 2	3 3 3	80 60 20
Total available Time (mins/day)	240	230	430	428	426	423	

Calculating Simplex Optimization Using LCI Data

Equation

s.t $0.3x_1 + 0.2x_2 + 0.1x_3 + s_1 = 280$

$0.3x_1 + 0.2x_2 + 0.1x_3 + s_2 = 260$

$3x_1 + 3x_2 + 3x_3 + s_3 = 378$

$2x_1 + 2x_2 + 2x_3 + s_4 = 376$

$2x_1 + 2x_2 + 2x_3 + s_5 = 375$

$3x_1 + 3x_2 + 3x_3 + s_6 = 372$

Max P = $280x_1 - 260x_2 - 378x_3 - 376x_4 - 375x_5 - 372x_6 = 0$

$P = 100x_1 + 70x_2 + 20x_3$

$P - 100x_1 - 70x_2 - 20x_3 = 0$

Now the frame work is constructed. The coefficients of the problem variables (x_1, x_2, x_3) and slack variables (S_1, S_2, S_3, S_4, S_5, S_6) in the constraints are arranged appropriately and shown in Table 9.

Table 9: Simplex Table Setup for Louis Carter Industry

C_j	$100\ X_1$	$70\ X_2$	$20\ X_3$	S_1	S_2	S_3	S_4	S_5	S_6	b
S_1	0.3	0.2	0.1	1	0	0	0	0	0	280
S_2	0.3	0.2	0.1	0	1	0	0	0	0	260
S_3	3	3	2	0	0	1	0	0	0	378
S_4	2	2	2	0	0	0	1	0	0	376
S_5	2	2	2	0	0	0	0	1	0	375
S_6	3	3	3	0	0	0	0	0	1	372
P_j	-100	-70	-20	0	0	0	0	0	0	

The constant headed by b is included together with the check to provide a check on the numerical calculation as the simplex is developed as shown in the Table 9.

Table 9: Simplex Table Setup

C_j	X_1	X_2	X_3	S_1	S_2	S_3	S_4	S_5	S_6	b	Check
S_1	0.3	0.2	0.1	1	0	0	0	0	0	280	933.3
S_2	0.3	0.2	0.1	0	1	0	0	0	0	260	866.6
S_3	3	3	2	0	0	1	0	0	0	378	126.0
S_4	2	2	2	0	0	0	1	0	0	376	188.0
S_5	2	2	2	0	0	0	0	1	0	375	187.5
S_6	3	3	3	0	0	0	0	0	1	372	124.0
P_j	-100	-70	-20	0	0	0	0	0	0		

Step 1

The highest most negative value is chosen as the column -100

Step 2

Divide the value in the b column by the values in the column of step 1 i.e.

$\frac{280}{0.3} = 933.3, \frac{260}{0.3} = 866.6,\ \frac{378}{3} = 126,\ \frac{376}{2} = 188,\ \frac{375}{2} = 187.5,\ \frac{372}{3} = 124$

Step 3

The intersection of the row and column gives the pivot number

Table 10: First Iteration

C_j	X_1	X_2	X_3	S_1	S_2	S_3	S_4	S_5	S_6	b	Check
S_1	0.3	0.2	0.1	1	0	0	0	0	0	933.3	9
S_2	0.3	0.2	0.1	0	1	0	0	0	0	866.6	10
S_3	3	3	2	0	0	1	0	0	0	126	126
S_4	2	2	2	0	0	0	1	0	0	188	188
S_5	2	2	2	0	0	0	0	1	0	187.5	187.5
S_6	1	1	1	0	0	0	0	0	0.3	124	124
P_j	-100	-25	15	0	0	0	0	0	0	0	

We replace the row with the values obtained as shown in Table 11.

C_j	X_1	X_2	X_3	S_1	S_2	S_3	S_4	S_5	S_6	b
S_1	0	-0.1	-0.2	1	0	0	0	0	0	242.8
S_2	1	-0.1	0.2	0	1	0	0	0	0	222.8
S_3	1	0	-1	0	0	1	0	0	0	6
S_4	0	0	0	0	0	0	1	0	0	128
S_5	0	0	0	0	0	0	0	1	0	127
S_6	1	1	1	0	0	0	0	0	1	124
P_j	0	30	80	0	2	0	0	0	30	12400

We now have a non negative value in our key row hence we stop our iteration process.

$P_{max} = 12400$

LCI Custard Production and Cost for March 2013

The data on Table 5 was collected on hourly basis from the factory for a period of one month on a daily basis and from each batch of production in March, 2013 and classified into columns. The quantity of custard produced for various sizes, cost price, selling price and profit made for the month of March 2013 were noted.

Table 5: Daily Quantity and Total Sales of Custard for the Month of March

Day	Number of mixes	Qty of custard packs produced			Number of cartoons	Cost price (₦)	Selling price (₦)	Profit (₦)
		Large	medium	Small				
Day 1	7	437	0	0	109	152600	196200	43600
Day 2	4	0	0	1333	55	121000	132000	11000
Day 3	9	562	0	0	140	168000	252000	84000
Day 4	7	0	583	0	145	145000	203000	58000
Day 5	8	500	0	0	125	150000	273600	123600
Day 6	7	0	583	0	145	145000	203000	58000
Day 7	7	437	0	0	109	152600	196200	43600
Day 8	4	0	0	1333	55	121000	132000	11000
Day 9	7	437	0	0	109	152600	196200	43600
Day 10	8	0	664	0	166	166000	232400	66400
Day 11	8	500	0	0	125	150000	273000	123000
Day 12	7	437	0	0	109	152600	196200	43600
Day 13	6	0	499	0	124	124000	173600	49600
Day 14	4	0	0	1333	55	121000	132000	11000
Day 15	8	0	664	0	166	166000	232400	66400
Day 16	7	437	0	0	109	152600	196200	43600
Day 17	7	437	0	0	109	152600	196200	43600
Day 18	6	0	0	1998	83	182600	199200	16600
Day 19	7	437	0	0	109	152600	196200	43600
Day 20	3	0	0	999	41	90200	98400	8200
Day 21	8	500	0	0	125	150000	273600	123600
Day 22	8	500	0	0	125	150000	273600	123600
Day 23	7	437	0	0	109	152600	196200	43600
Day 24	7	437	0	0	109	152600	196200	43600
Day 25	8	500	0	0	125	150000	273600	123600
Day 26	4	0	0	1333	55	121000	132000	11000
TOTAL	173	6995	2993	8329	2836	3794200	5255200	1461000

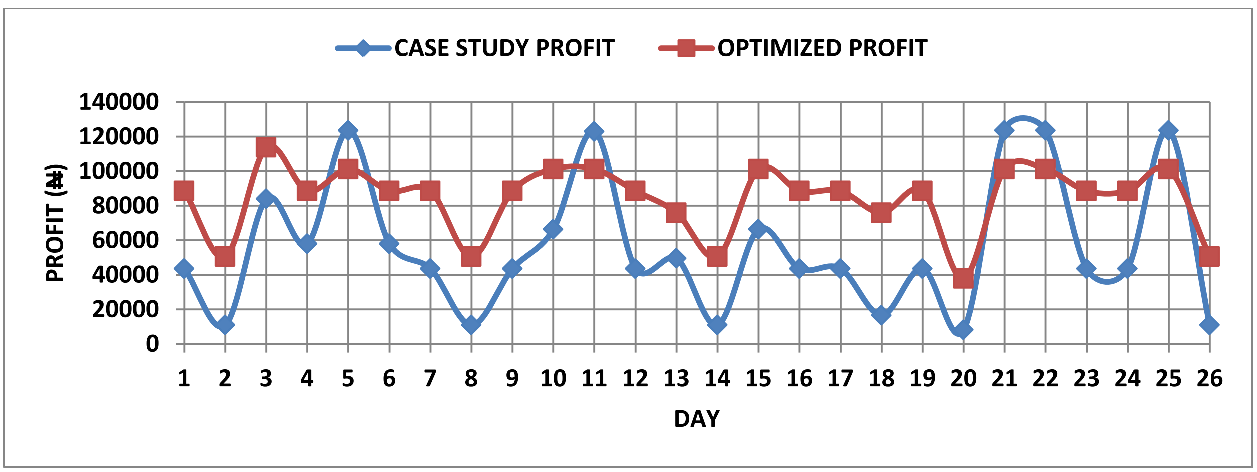


Fig. 2: LCI Profit and Optimized Profit for the Month of March, 2013 for LCI

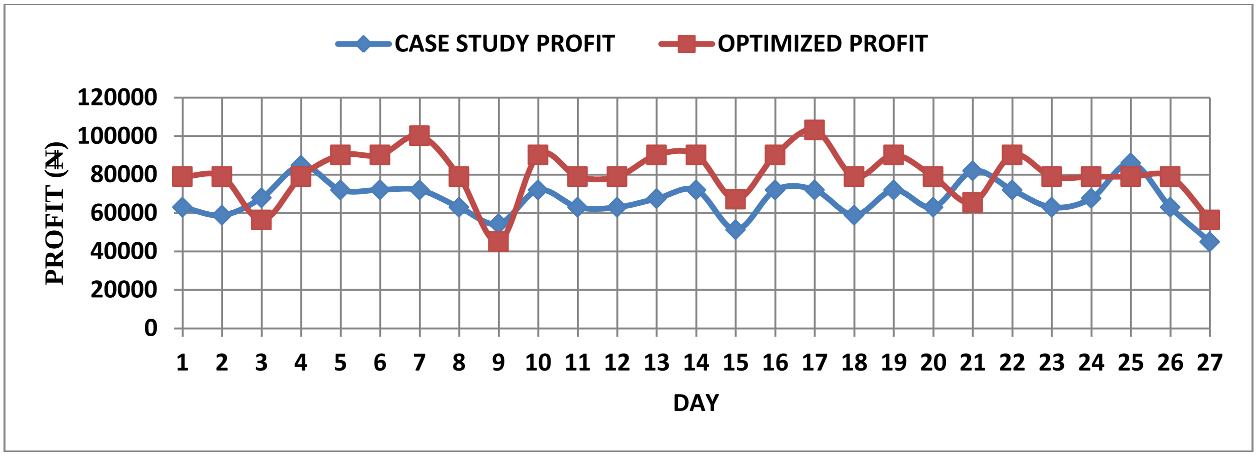


Fig. 3: KGFI Profit and Optimized Profit for the Month of August, 2013

Fig 2 and 3 show the case studies profit and optimized profit for LCI and KGFI for the months of March 2013 and August 2013, respectively. For the month specifically analyized, it can be seen that the profit that the company makes someday are greater that the profit they can make when optimized. Specifically, LCI made more profit in days 5, 11, 21, 22 and 25 while when optimized, more profit is made in the remaining 21 days of the 26 days under consideration, as clearly depicted in Fig 2. Similarly, KGFI made more profits in days 3, 4, 9, 21 and 25 while when optimized made more profit in the remaining 22 days. The total profit made for the 26 days by LCI is One million, four hundred and sixty one thousand naira (₦1,461,000), as against two million one hundred and eighty nine thousand, one hundred and forty two naira (₦ 2,189,142), when optimized. By the same token, KGFI has a total profit of One million, seven hundred and fifty eight thousand, one hundred naira (₦ 1,758,100), as against two million, six hundred and sixty three thousand, five hundred and twenty three naira only (₦ 2,663,523). The marginal profit (extra profit) gained when optimized as shown by LCI and KGFI are seven hundred and twenty eight thousand, one hundred and forty two naira (₦728,142) and nine hundred and five thousand four hundred and twenty three naira (₦905,423) which indicates that the optimization is highly beneficial.

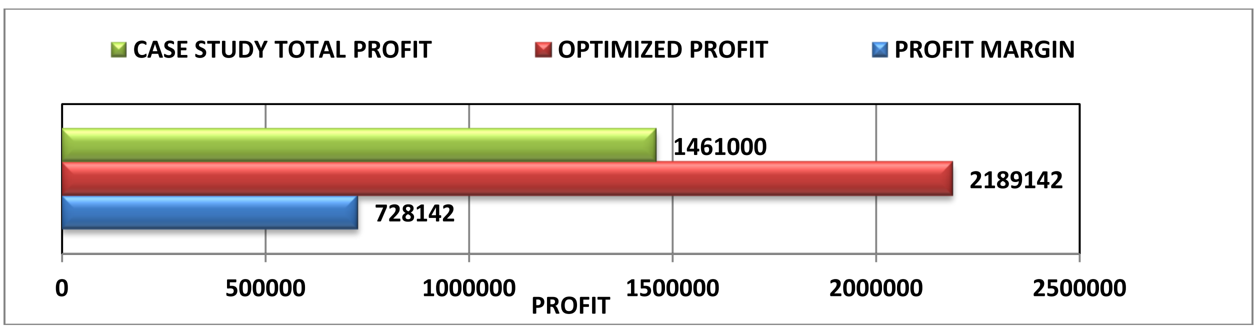


Fig. 4: LCI Case Study Profit, Optimized Profit and Profit Margin

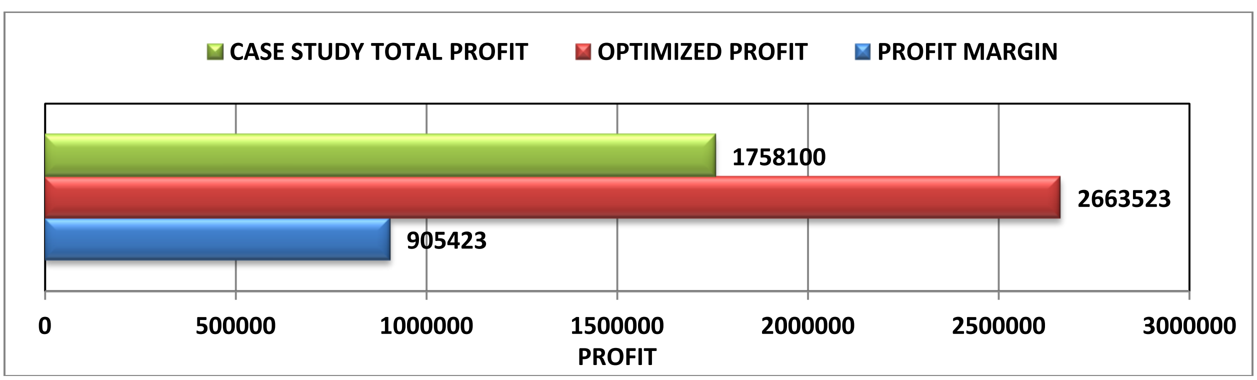
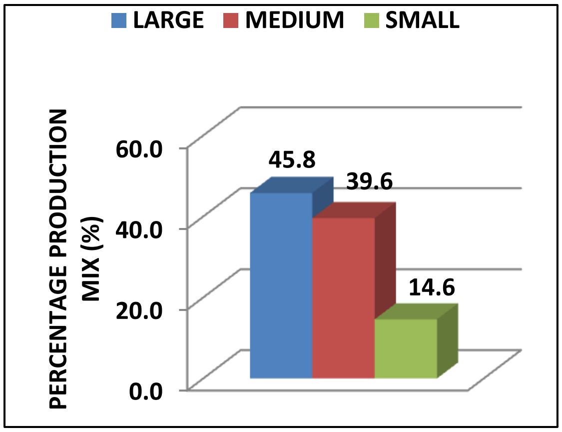


Fig. 5: KGFI Case Study Profit, Optimized Profit and Profit Margin

Beyond the cost implications, the percentage of custards per batch for each of the three different sizes of custard shown in Fig. 6 and Fig. 7, respectively.



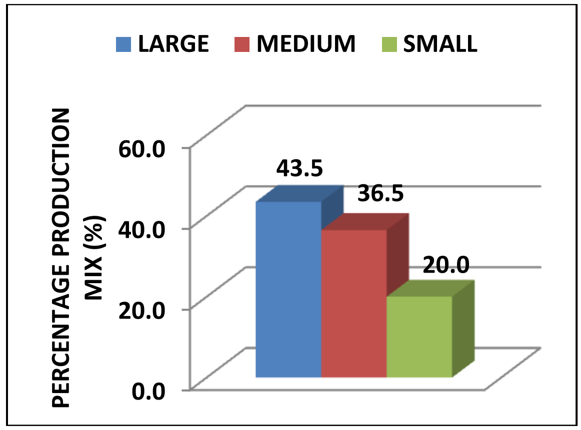


Fig. 6: Percentage Production Mix for LCI **Fig. 7: Percentage Production Mix for KGFI**

Conclusion

In this work, various process time and costs for LCI and KGFI were analyzed. Simplex method of optimization was employed in determining the appropriate production mix and associated total profit for both industries. The case study of LCI results gave an optimal production mix of 45.8%, 39.6% and 14.6% for large, medium and small sized custard, respectively, with an increase in profit margin to 49.8% translating into ₦728,142:00 for the month of March, 2013. Similarly, KGFI have an optimal production mix of 43.5%, 36.5% and 20% for large, medium and small sized custard with an increase in profit margin to 51.5% translating into ₦ 905,423.00 for the month of August, 2013. This study has been established that simplex method of optimization is a good model for the analysis of appropriate production proportion problem. It gives product mix that maximizes profit and minimizes cost.

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