Modeling Linear Programming Problem Using Microsoft Excel Solver

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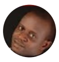
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Modeling Linear Programming Problem Using Microsoft Excel Solver

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Abstract

This study demonstrated how Microsoft Excel Solver is applied to linear programming problems. The study considered an illustration culled from Agbadudu (1996) of a tailor making two garments (dress and suit) with three resources (constraints) namely: cotton, silk and wool. Microsoft Excel Solver was used to find an optimal solution to the problem of resource allocation confronting the tailor. Further analyses were done using *Answer* and *Sensitivity Reports* to provide robust solutions that can serve as a guide to the tailor in making appropriate decisions. Scenario analysis using *Data Table*, a *What-If Analysis* tool in Microsoft Excel 2007 version was used to generate possible profits that the tailor can make from producing different units of garments (dress and suit). It was found that the tailor can produce 70 units and 20 units of dress and suit respectively to maximize profit based on the resources at his disposal; while the maximum profit the tailor can get for the given period is ₦14,500. It was therefore recommended that business owners, managers and students should be exposed to the knowledge of linear programming problems through the use of computer software such as Microsoft Excel Solver so as to enhance their decision making skills.

Keywords: Garment, Linear Programming, Microsoft Excel, Solver, What-If Analysis.

Introduction

Most organizations, big or small, private or public, are confronted with a problem of limited supply of resources. These resources include: men, machines, money and materials, among others. Limited supply and availability of resources calls for management to find the best means of allocating its resources in order to maximize profit, minimize loss or utilize the production capacity to its maximum level. Linear programming models have been adjudged as one of the operations research tools for allocating scarce resources in an efficient manner and they have been extensively applied both in public and private sectors (Agbadudu, 1996; Ekoko, 2011).

The use of linear programming in management and decision making originated in the 1940s during World War II, when a team of British scientists applied it in decisions among the British armed forces regarding the best utilization of war materials (Igwe, Onyenweaku & Tanko, 2013; Taha, 2011). Since then, linear programming had been applied in different areas. In management, linear programming has been used to solve media selection problems, portfolio selection problems, profit planning problems, transportation problems, assignment and sequencing problems, manpower scheduling problem, amongst others (Gupta & Hira, 2011; Osamwonyi & Tebekaemi, 2007). Different methods are used in solving linear programming problems. These methods include: graphical method, simplex method, dual-simplex method, Big-M methods amongst others. Most times, students are taught manually on how to use these methods to solve problems. This creates a lot of challenges for the students as some of the methods are complex for them to easily understand. Apart from the complexity and intricacies involved in using some linear programming methods, solving them manually can result in making mistakes.

It is on this basis that this study focused on the application of Microsoft Excel Solver to linear programming problems. The choice of Microsoft Excel Solver is based on the fact that it can easily be accessed, flexible in nature and has the capacity to solve complex problems with high level of accuracy. Solver tool is used to determine the maximum or minimum value of one cell by changing other cells. In doing this, an illustration culled from Agbadudu (1996) of a tailor making two garments (dress and suit) with three resources (constraints) namely: cotton, silk and wool was used. *Answer* and *Sensitivity Reports* were also generated to provide guides to the tailor in making appropriate decisions.

Concept of Linear Programming

Linear programming is a mathematical technique for finding the best uses of a firm's organization's limited resources (Agbadudu, 1996). Linear programming problems are concern with the efficient use or allocation of scarce resources to meet desired objectives. The word *Linear* means that the relationships are those represented by straight lines, while the word *Programming* means taking decisions systematically. Thus, linear programming can be described as a decision making technique under a given constraints on the assumption that the relationships amongst the variables representing different phenomena happen to be linear (Anyebe, 2001). According to Agbadudu (1996, p.6), "the objective of linear programming is to seek values of some controllable variables so as to determine the most efficient method of allocating these resources to activities so that a measure of performance is optimized."

Different authors (Agbadudu, 1996; Anyebe, 2001; Gupta & Hira, 2011; Verma, 2010) have identified some basic assumptions on which linear programming model is based. These include:

i. Additivity: It refers to the value of the objective function for the given values of decision variables and the total sum of resources used must be equal to the sum of contribution (profit or cost) earned from each decision variable and the sum of the resources used by each decision variables respectively;
ii. Divisibility: It means the value of a controllable variable can be fraction, not necessarily a whole number;
iii. Deterministic: It means all model coefficients are known, and hence constant in the period under consideration;
iv. Proportionality: It means the objective function and constraints must be linear;
v. Certainty: The various parameters, namely, the objective function coefficients, RHS coefficients of the constraints and resource values in the constraints are certainly and precisely known and that their values do not change with time;
vi. Finite choices: It means a limited number of choices are available to the decision maker and that the decision variables are interrelated and non-negative.

Linear programming is one of the most widely applied techniques of operations research in business and industry (Gupta & Hira, 2011). Industrial applications of linear programming include solving product mix problems, blending problems, production scheduling problems, trim loss problems, assembly-line balancing and make-or-buy (sub-contracting) problems, among others. Linear programming as an operations research technique can be applied in solving management-related problems. Some of the applications of linear programming to managerial problems include solving media selection problems, portfolio selection problems, profit planning problems, transportation problems, assignment problems, manpower scheduling problems (Gupta & Hira, 2011; Osamwonyi & Tebekaemi, 2007). Other areas where linear programming has been applied include quality control inspection, determination of optimal bombing patterns, design of war weapons, vendor quotation analysis, scheduling military tanker fleet, fabrication scheduling, and computations of maximum flows in network and so on (Anyebe, 2001).

Although linear programming has a numerous advantages and applications, it is not free from limitations. According to Vinay (2015), "a primary requirement of linear programming is that the objective function and every constraint must be linear. However, in real life situations, several business and industrial problems are nonlinear in nature. Linear programming takes into account a single objective only, that is, profit maximization or cost minimization. However, in today's dynamic business environment, there is no single universal objective for all organizations. Also, parameters appearing in linear programming are assumed to be constant, but in real life situations it is not so." Linear programming also presents trial and error solutions to problems and it is difficult to find real optimal solutions to various business problems. In spite of these limitations, linear programming is extensively used in taking business decisions. Most of the limitations of linear programming can be solved by developing nonlinear programming techniques (Pradeep, 2015).

Formulation of Linear Programming Models

According to Anyebe (2001), there are three basic steps in constructing a linear programming model. These steps are briefly explained as follows:

Step I: Identification of the decision variables: Identify the variables to be determined (decision variables) and represent them in terms of algebraic symbols. Then impose the non-negativity condition on them.

Step II: Identification of the constraints: These are the limitations under which one has to plan and decide the restrictions imposed on the decision variables. Such restrictions or constraints are expressed as linear equation or inequalities.

Step III: Identification of the objective function: The objective function also known as the criterion function states the determinants of the quality to be either maximized or minimized. An objective function should include all the possible activities with profit or cost coefficients per unit of production or acquisition. The goal is to either maximize the function or minimize it. The objective function is represented as a linear function of the decision variables which is to be maximized or minimized.

The general form of linear programming problem for a maximization case is given by Verma, (2010) as:

$$Maximize\ Z = C_1X_1 + C_2X_2 + \cdots + C_nX_n \qquad (objective\ function)$$

$$\begin{aligned} subject\ to: \quad & a_{11}X_1 + a_{12}X_2 + \cdots + a_{1n}X_n \leq b_1 \\ & a_{21}X_1 + a_{22}X_2 + \ldots + a_{2n}X_n \leq b_2 \\ & \quad . \qquad . \qquad . \qquad . \qquad (Explicit\ constraints) \\ & \quad . \qquad . \qquad . \qquad . \\ & a_{m1}X_1 + a_{m2}X_2 + \cdots + a_{mn}X_n \leq b_n \end{aligned}$$

$$\text{and } X_1, X_2, \ldots X_n \geq 0 \qquad (non-negativity\ constraint)$$

Where:

Z = the value of overall measure of performance

X_n= levels of activity $(1, 2, \ldots n)$

a_{ij} = the amount of resources i consumed by each unit of activity j

b_i = the amount of resources that is available for allocation to activities $(j = 1, 2, \ldots m)$

C_1 = increase in Z that will result from each unit increase in level of activity

$X_1, X_2, \ldots X_n$ are decisional variables

C_1, b_i, and $a_{ij}(i = 1, 2, \ldots m\ and\ j = 1,2, \ldots n)$ are the inputs constants also referred to as the parameters of the model.

Description of Microsoft Excel Solver

Linear programming problems can be solved using spreadsheet. Most spreadsheets have in-built optimization routines that can easily be used. Microsoft Excel has an optimization tool called *Solver*. Solver is used to determine the maximum or minimum value of one cell by changing other cells. According to FrontlineSolver (2015), solver is used to "find better ways to allocate scarce resources, maximize profits or minimize costs or risks, in a wide range of applications in finance and investment, marketing, manufacturing and production, distribution and logistics, purchasing, and human resources, science and engineering, among others."

The Microsoft Excel 2007 version solver feature is usually hidden and can be brought out to the menu by clicking the button sequencing: Office button → excel options → add- ins → analysis tool pack and solver add-in (Kumari & Kumar, 2012). Figure 1 below shows the dialogue box for the Solver Parameters.

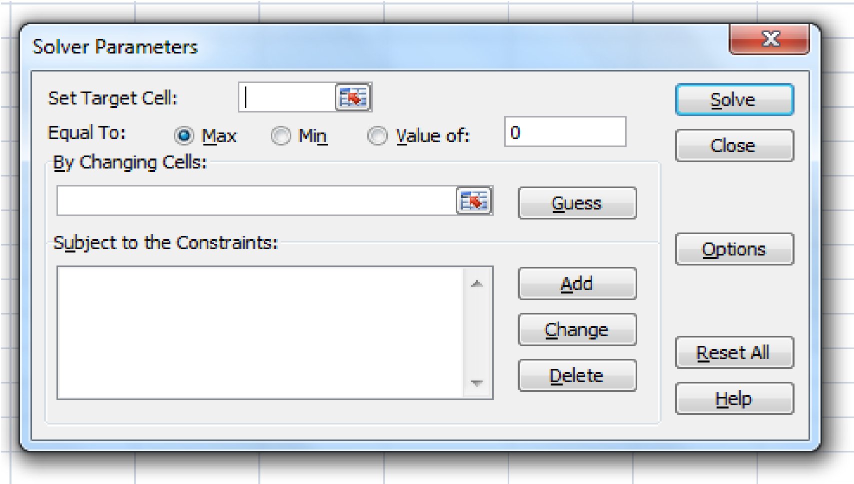

Figure 1: Microsoft Excel Solver Parameter

The components of Solver Parameters such as set target cell, equal to, by changing cells, subject to the constraints, add, change, delete and solve buttons are explained as presented in http://download.microsoft.com as follows:

Set target cell: This is where the objective function (or goal) to be optimized is indicated. This cell contains a formula that depends on one or more other cells (including at least one "changing cell").

Equal to: This provides the option of treating the *Target Cell* in three alternative ways. *Max* (the default) tells Excel to maximize the Target Cell; *Min* to minimize; while *Value* is used to reach a certain particular value of the Target Cell by choosing a particular value of the endogenous variable.

By changing cells: This is where the adjustable cells (that is, endogenous variables) are indicated. As in the *Set Target Cell* box, it is possible to either type in a cell address or click on a cell in the spreadsheet. Excel handles multivariable optimization problems by giving room for additional cells in the *By Changing Cells* box. Each non-contiguous choice variable is separated by a comma.

Subject to the constraints: This is used to impose constraints on the endogenous variables. *Add, change and delete buttons*: These are used to create and alter the set of constraints. These buttons lead to dialog boxes where one can indicate choices, and then click on OK.

Solve button: This is the last thing to be done in the Solver Parameters dialog box. It is used to get Excel's Solver to find a solution to a problem.

Apart from the aforementioned components of *Solver Parameters*, Solver has the capacity to provide robust results to a linear programming problem by generating answer report and sensitivity report. These two important reports are explained as follows:

Answer Report: FrontlineSolver (2015) opines that answer report "provides basic information about the decision variables and constraints in a model. It gives a quick way to determine which constraints are "binding" or satisfied with equality at the solution, and which constraints have slack. The *Answer Report* records the message that appeared in the Solver Results dialog, the solving method used to solve the problem, Solver Option settings, and statistics such as the time, iterations and sub-problems required to solve the problem. *Answer Report* contains objective function and decision variables, with their original value and final values. Next are the constraints, with their final cell values; a formula representing the constraint; a "status" column showing whether the constraint was binding or non-binding at the solution; and the slack value – the difference between the final value and the lower or upper bound imposed by that constraint."

Sensitivity Report: According to FrontlineSolver (2015), sensitivity report "provides classical sensitivity analysis information for both linear and nonlinear programming problems, including dual values (in both cases) and range information (for linear problems only). The dual values for (non-basic) variables are called *Reduced Costs* in the case of linear programming problems and *Reduced Gradients* for nonlinear problems. The dual values for binding constraints are called *Shadow Prices* for linear programming problems and Lagrange Multipliers for nonlinear problems."

Dual values are the most basic form of sensitivity analysis information. According to FrontlineSolver (2015), "the dual value for a variable is non-zero only when the variable's value is equal to its upper or lower bound at the optimal solution. The dual value measures the increase in the objective function's value per unit increase in the variable's value. The dual value for a constraint is non-zero only when the constraint is equal to its bound. This is called a *binding* constraint, and its value was driven to the bound during the optimization process. Moving the constraint left hand side's value away from the bound will *worsen* the objective function's value; conversely, "loosening" the bound will *improve* the objective. The dual value measures the increase in the objective function's value per unit increase in the constraints bound."

In linear programming problems, FrontlineSolver (2015) asserts that "the dual values are *constant* over a range of possible changes in the objective function coefficients and the constraint right hand sides. The *Sensitivity Report* for linear programming problems includes this range of information. For each decision variable, the report shows its coefficient in the objective function, and the amount by which this coefficient could be increased or decreased without changing the dual value. For each constraint, the report shows the constraint right hand side, and the amount by which the RHS could be increased or decreased without changing the dual value."

Illustration of Application of Solver to Linear Programming Problem

In this section, Microsoft Excel Solver is used to solve a maximization case of a linear programming problem for a tailoring outfit. The problem is presented as follows:

A tailor has the following materials available for production of dress and suit; 160 square metres of cotton, 110 square metres of silk and 150 square metres of wool. A dress requires the following: 2 square metres of cotton and 1 square metre each of silk and wool. A suit requires 1 square metre of cotton, 2 square metres of silk and 3 square metres of wool. If the profit realized from a dress and a suit is respectively ₦150 and ₦200, how many each garment should the tailor make in order to obtain maximum profit in the period under consideration?

The problem is represented in tabular form as follows:

Table 1: Data for the problem

Materials/Products	**Dress (X_1)**	**Suit (X_2)**	**Availability of Materials (Sq metre)**
Cotton	2	1	160
Silk	1	2	110
Wool	1	3	150
Profit	₦150	₦200	

Source: Culled from Agbadudu (1996; p.10)

The problem in Table 1 above can be expressed mathematically as:

Maximize $Z = 150X_1 + 200X_2$ (Objective function)

Subject to: $2X_1 + X_2 \leq 160$ (Cotton Constraint)

$X_1 + 2X_2 \leq 110$ (Silk Constraint)

$X_1 + 3X_2 \leq 150$ (Wool Constraint)

$X_1, X_2 \geq 0$ (Non-Negative Constraint)

The above problem is presented in Excel spreadsheet (Figure 2) by describing each variable, the objective function, and all the constraints (Under column B). The appropriate formulae for computing the objective function (Z); cotton, silk and wool constraints are shown under column C of the spreadsheet.

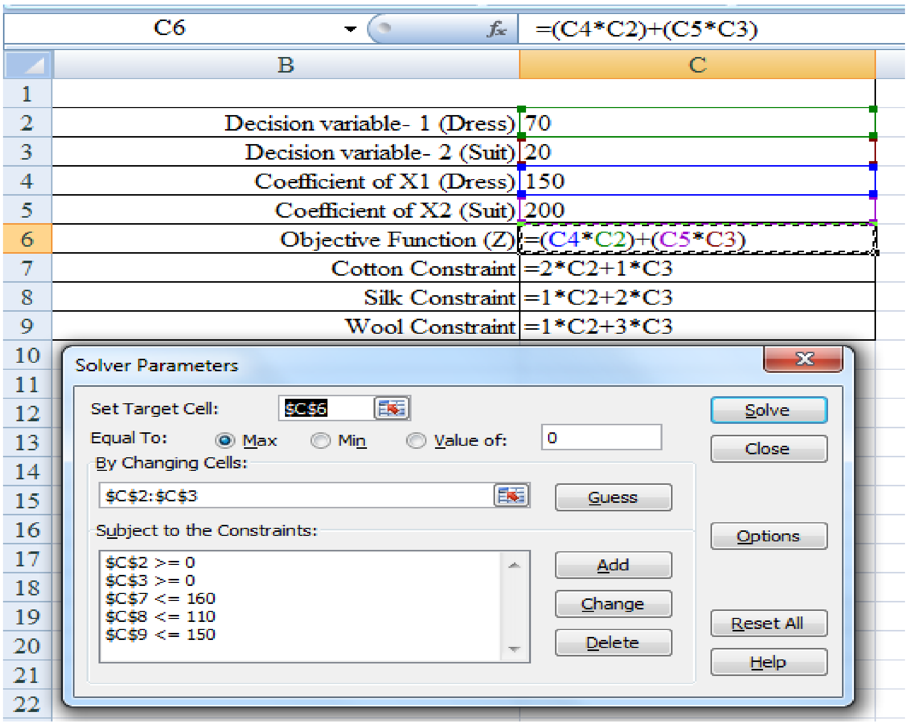

Figure 2: Spreadsheet showing formula and solver parameters

From Figure 2 above, in terms of cell references, the goal is to maximize the objective function (C6) by modifying the entries in C2 and C3 for decision variable 1 (dress) and decision variable 2 (suit) respectively. To achieve this, click on cell C6 (the cell containing the objective function that we want to maximize) and activate the *Solver Tool* under *Data Menu.* Once the *Solver Parameters* dialog box is activated as shown in Figure 2 above, the necessary parameters such as: set target cell (C6); Max (for maximization case); By changing cells (highlight C2 to C3); and subject to the constraints (a place to enter the explicit constraints [that is, cotton, silk and wool] and non-negativity constraints) are entered accordingly. Finally, click on *Solve* button, the computer will automatically calculate the optimum solution displaying the required values for cells C2 and C3, and showing the maximum value of Z in cell C6.

The results emanating from the above process is displayed in Figure 3 below:

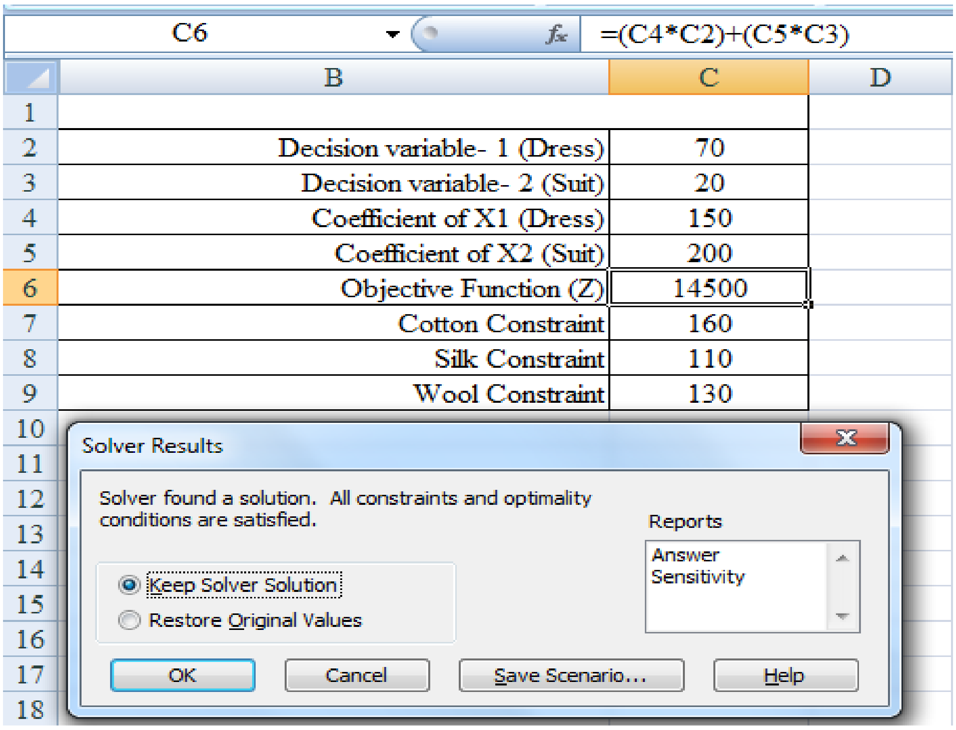

Figure 3: Spreadsheet showing optimal solutions and solver results

The above result shows that the optimum solution obtained by the solver for decision variable 1 (dress) and decision variable 2 (suit) are 70 units and 20 units respectively; while the maximum profit the tailor can get for the given period is ₦14,500. For further analysis, click on *Answer* and *Sensitivity* under *Reports* for a more comprehensive solutions to the problem.

Answer Report

Table 2 below shows the *Answer Report* that contains the original guess for the solution and the final value of the solution. The report also shows the objective function values for the original guess and final value as well as the constraints values.

Table 2: Microsoft Excel 12.0 Answer Report

Target Cell (Max)

Cell	Name	Original Value	Final Value
C6	Objective Function (Z)	0	14500

Adjustable Cells

Cell	Name	Original Value	Final Value
C2	Decision variable- 1 (Dress)	0	70
C3	Decision variable- 2 (Suit)	0	20

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
C7	Cotton Constraint	160	C7<=160	Binding	0
C8	Silk Constraint	110	C8<=110	Binding	0
C9	Wool Constraint	130	C9<=150	Not Binding	20

Table 2 above shows the optimal value of the objective function (Z) which is ₦14,500. The result also reveals the optimal values (units) of the decision variables, that is, dress and suit to be 70 units and 20 units respectively. With respect to the constraints, the report also indicates that cotton and silk constraints are binding; this implies that cotton and silk materials are fully utilized in the final solution. The wool constraint is not binding with 20 units of slack. This means there is 20 units of wool materials that are not being used to produce the final solution.

Sensitivity Report

The *Sensitivity Report* in Table 3 details how changes in the coefficients of the objective function affect the solution and how changes in the constants on the right hand side (RHS) of the constraints affect the solution. Under the heading *Adjustable Cells*, the three columns labelled *Objective Coefficient*, *Allowable Increase*, and *Allowable Decrease* give the conditions for which the solution (70, 20) remains optimal. For instance, it can be deduced from the result (Table 3) that if the coefficient on *Dress* is raised to 150+250=400, or decreased to 150 - 50=100, the optimal production plan of making 70 *Dresses* and 20 *Suits* will be met all things being equal. Similarly, if the coefficient on *Suit* is raised to 200+100=300, or decreased to 200-125=75, the optimal production plan remains unchanged. In each case, the range of values that the coefficient can take can be calculated by subtracting the allowable decrease from the coefficient or adding the allowable increase to the coefficient. For application purpose, this means that if the profit per *dress* varies between 100 and 400 or the profit per *suit* varies between 75 and 300, the optimal production plan of producing 70 *dresses* and 20 *suits* for the period under consideration will still be achieved.

Table 3: Microsoft Excel 12.0 Sensitivity Report

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
C2	Decision variable- 1 (Dress)	70	0	150	250	50
C3	Decision variable- 2 (Suit)	20	0	200	100	125

Constraints

Cell	Name	Final Value	Shadow Price	Constraint RHS	Allowable Increase	Allowable Decrease
C7	Cotton Constraint	160	33.33	160	60	60
C8	Silk Constraint	110	83.33	110	12	30
C9	Wool Constraint	130	0	150	1E+30	20

The *Constraints* part of the *Sensitivity Report* examines how changes to the right hand side (RHS) of any constraint affect the optimal solution. A change to the constant on the right hand side of a constraint changes the size of the feasible region. Increasing the right hand side of any constraint with positive coefficients shifts the border matching the constraint up. Decreasing the right hand side of any constraint with positive coefficients shifts the border matching the constraints down. The shadow price indicates how the objective function will change when the constant on the right hand side is changed. In Table 3, the shadow price for the cotton constraint is ₦33.33. This indicates that if the capacity is increased by 1 (from 160 to 161), the corresponding profit at the optimal solution will increase by ₦33.33. In the same vein, the profit at the optimal solution will decrease by ₦33.33 if cotton material is decreased by 1unit (from 160 to 159).

In both cases, since the size of the feasible region changes, the optimal solution will change to a new value. These changes are valid over a range of changes indicated by the values in the *Allowable Increase* and *Allowable Decrease* columns. As long as the right hand side stays within 160-60=100 to 160+60=220, the shadow price remains valid. The same applies to the silk constraint that is binding. If the unit of material for silk increases/decreases by 1 unit in a range of values from 110-30=80 units to 110+12=122 units, the profit will increase/decrease by ₦83.33.

The sensitivity analysis for wool constraint which is not binding is different. At the optimal solution, changes to the right hand side do not affect the profit as long as the right hand side is not decreased too much. This means that the shadow price is ₦0. The only way this would change is if the number of units for wool is dropped to 130 units. At this point, there is no longer any slack at the optimal solution and the constraint becomes binding. This fact is evident in the report under the *Allowable Decrease* column. For the wool constraint, the shadow price of ₦0 is applicable for a decrease of 20 units from 150 units to 130 units. The *Allowable Increase* for this constraint is shown as 1E+30, that is, a Microsoft Excel's way of showing infinity. This implies that the right hand side can be increased by any units without changing the shadow price. This assertion is sensible because increasing the right hand side (adding more units for wool material) simply adds more unutilized materials to the constraint and will not change the feasible region.

Profit Simulation

In illustrating the possible profits that the tailor can make by making different units of dress and suit, ***Data Table***, a ***What-If Analysis tool*** in Microsoft Excel was used. In doing this, a range of 0 - 70 and 0 - 20 was set for dress and suit respectively. The result is shown in Table 4 below:

Table 4: Possible Profits from Combination of Different Units of Dress and Suit

		Different Units of Dress							
	14,500	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**
Different Units of Suit	**0**	-	1,500	3,000	4,500	6,000	7,500	9,000	10,500
	2	400	1,900	3,400	4,900	6,400	7,900	9,400	10,900
	4	800	2,300	3,800	5,300	6,800	8,300	9,800	11,300
	6	1,200	2,700	4,200	5,700	7,200	8,700	10,200	11,700
	8	1,600	3,100	4,600	6,100	7,600	9,100	10,600	12,100
	10	2,000	3,500	5,000	6,500	8,000	9,500	11,000	12,500
	12	2,400	3,900	5,400	6,900	8,400	9,900	11,400	12,900
	14	2,800	4,300	5,800	7,300	8,800	10,300	11,800	13,300
	16	3,200	4,700	6,200	7,700	9,200	10,700	12,200	13,700
	18	3,600	5,100	6,600	8,100	9,600	11,100	12,600	14,100
	20	4,000	5,500	7,000	8,500	10,000	11,500	13,000	***14,500***

Table 4 above shows that the optimal profit that the tailor can make is ₦14,500 by producing 70 dresses and 20 suits. Any production level that is below the optimal point (70, 20) will produce a lesser profit. For instance, if 50 dresses and 10 suits are made, the profit will be ₦9,500 which is below the optimal profit of ₦14,500. The usefulness of the above scenario is to guide the tailor (decision maker) in making appropriate combinations of available resource to produce different units of dress and suit assuming the resource at his disposal will not be enough to produce up to the optimal points of 70 and 20 units of dress and suit respectively. Also, the result will serve as a production guide on possible profits level the tailor can attain when there is fluctuation in demands for his products.

Conclusion

In this study, the knowledge of Microsoft Excel Solver was highlighted and demonstrated in solving linear programming problem. Linear programming problems in general are concerned with the use or allocation of scarce resources (labour, materials, time, capital and so on) in the best possible manner that would maximize profit or minimize cost. An illustration culled from Agbadudu (1996) of a tailor making two garments (dress and suit) with three resources (constraints) namely: cotton, silk and wool was used for demonstration purpose. Solver was used to find optimal solutions to the problem of resource allocation confronting the tailor (decision maker). It was found that the optimal units of dress and suit the tailor can produce to maximize profit are 70 units and 20 units respectively; while the maximum profit the tailor can get for the given period is ₦14,500. Further analyses were conducted using *Answer* and *Sensitivity Reports* to provide robust solutions that can serve as a guide to decision makers in making appropriate decisions. Finally, *Data Table*, a *What-If Analysis* tool in Microsoft Excel was used to generate possible profits that the decision maker can attain from making different units of his products (dress and suit).

Recommendations

This study recommends that the use of computer software such as Microsoft Excel Solver which can easily be accessed, flexible in nature and have the capacity to handle complex problem with high accuracy level should be encouraged in training future managers (business administrators) instead of using only manual methods that is rigorous, and seemingly difficult for individuals that may not have flair for calculations. Also, business owners can benefit substantially from the knowledge of linear programming problems through the use of computer software such as Microsoft Excel Solver; they should acquire training on how to use it for timely and appropriate decision making. Finally, it is suggested that future studies should focus on other areas of application of Microsoft Excel Solver to operations research problems such as transportation model, assignment model, goal programming, integer programming and so on.

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