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Incorporating a Decision Maker's Value Judgement in Linear Programing Formulation

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ABSTRACT

Conventional (tradition) linear programming (LP) formulation assumes that the decision variables have equal preferences. This assumption thus neglects the unequal preferences that a decision maker may consider in terms of attaching priorities to the decision variables. In this research, a modified form of LP model formulation was carried out. A furniture making company (producing six different furniture products)was used as a case study for the model formulation. The modified form incorporated the value judgment of a decision maker in terms of utility (priority) as a result of some criteria the decision maker uses in assessing the alternative decision variables. Analytic hierarchy process (AHP) was used to determine the priority rankings of the criteria and the decision variables derived from the subjective assessment made by the Proprietor of the company. Saaty's 9-point scale was used to quantify the verbal assessment from which pairwise comparism matrices for both the criteria and the decision variables were developed. Ease of construction, Ease of delivery and sales patronage were identified as criteria the proprietor(owner) of the company uses in prioritizing the contribution of the decision variables to the optimum solution. Consequently, the overall weights and priorities ranking the six furniture products were determined as follows: 12 spring beds (x_1) ranked first with weight of 0.3074, 10 spring beds (x_2) ranked second with weight of 0.2893, wardrobes (x_3) ranked third with weight of 0.1282, office chairs (x_5) was ranked fourth with weight of 0.1188, office tables (x_4) ranked fifth with weight of 0.0874 and upholstery chairs (x_6) ranked sixth with weight of 0.0689. These weights were incorporated into both the objective function and the constraints simultaneously. The problem was formulated in two types: conventional LP formulation and the proposed LP-AHP formulation. Average monthly production schedules with associated average net profit were used as a bench mark for assessing the qualities of the optimum solutions obtained from the conventional LP formulation and the proposed LP-AHP. The optimum solutions obtained from the proposed formulation seem to provide more realistic solutions of the problem. Based on the outcome of the analyses of the results we therefore suggest that the value judgment of a decision maker should be incorporated into LP formulation.

Keywords: *AHP, Decision Maker, Decision Variables, Linear Programming, Optimum Solutions, Priority, Value Judgment.*

1. INTRODUCTION

Linear programming (LP) is a widely used classical optimization technique for the allocation of scarce resources. It derives its optimal solutions procedurally when the problem has been properly formulated in a mathematical form that specifies an objective function and constraints. The mathematical programe formulated exhibits linear relationship of the variables in both the objective function and the constraints and hence the name linear programe. The technique of LP was developed in the late 1940s to solve a number of resource allocation problems (Kolman and Beck, 1995). Wankhade and Lunge (2012) assert that LP has been utilized by many firms in making decisions about establishment of new industries and in deciding upon different methods of production, distribution, marketing and policy decision making and thus, LP is perhaps the most important and best-studied optimization model. The traditional approach of formulating LP considers quantitative factors such as resources available, per unit contribution of each of the variables, the technological transformation coefficients of each of the variables in each of the constraints.

The value judgment(s) of a decision maker or decision makers has not been incorporated into the LP formulations. Susilawati (2001) asserts that the LP model formulation, though an important technique for planning and allocating scarce resources, excluded qualitative factors such as social, politic or ethical issues which are very important in some cases and thus must be considered. Therefore, the need to incorporate qualitative information as value judgment(s) or utility of the decision variables into a an LP is crucial. This formed the basis for this research.

The Analytic Hierarchy Process (AHP) developed Saaty (1990) as a technique can be used to deal with problems involving consideration of multiple criteria at once. It has been extensively applied in complex decision-making problems of choice, prioritization and evaluation. Also, its ability to synthesize both tangible and intangible characteristics, to accommodate both shared and individual values and monitor the consistency with which a decision-maker makes his judgments made the AHP a widely used multiple criteria decision making(Lupetu, 2012; Vaiya and Kumar,2004).

Saaty *et al*(2003)and Saaty *et al* (2007) illustrated the use of AHP for allocation of intangible resources in LP by deriving relative important weightings as coefficients in either objective function or the constraints of the LP independently. This implies their arguments did not focus on weighing criteria and alternatives for incorporation into both the objective function and the constraints simultaneously.

Ada, Kazancoglu and Ozkan (2005) used AHP to determine weights for qualitative factors for incorporation into the objective function of LP formulated for a facility location problem. The LP model was broken into two components- one component was on quantitative factors and the other component for qualitative factors. AHP was applied to weigh the qualitative factors and quantitative data in respect of cost was used as coefficients for the quantitative factors. This also implies that AHP was not used to determine weight in order to prioritize alternative decision variables.

Chansa-ngavej and Sakchanalaya (2011) integrated LP-AHP in selecting production and distribution centres, amount of cement to be produced at each production centre and the amount to be distributed to each destination. In the study, AHP was used to evaluate group of Managers' decision to prioritize dispatching points. This implies that AHP after deriving optimal solutions from the LP of the transportation problem which was formulated using the conventional approach of the LP formulation. Hence AHP was not used to determine the weights of the alternative decision variables.

From the foregoing, it is evident that modeling LP with prior information from the decision maker using AHP is attainable. We therefore propose an approach of modeling LP with prior information, where the AHP technique serves as auxiliary information into the modeling of an LP.

In this research, the value judgment of a decision maker was incorporated into the decision variables in both the objective function and the constraints simultaneously in order derive optimum solutions for an LP problem. This research was conducted on a big furniture manufacturing company, Yola Adamawa State, Nigeria. The company produces different types of furniture for sale (whole sale and retail) in order to maximize profit. Interactions with the Proprietor of the company reveal that the productions of the different types of furniture were treated with some levels of differing preferences. This situation signified that the contributions of each of the products to the overall profit of the company was not only on the per unit monetary contributions but also the utility values (level of preferences) the Proprietor attaches to the products. Hence, necessitated the need to incorporate the value judgment of the Proprietor in formulating both the objective function and the constraints of the LP of the furniture production.
AHP, developed by Saaty (1990) was employed to determine the weights of criteria used to determine priority (ranking) of the alternative furniture products.

2. METHODOLOGY

The conventional approach used in formulating the linear programming problem, where only quantitative data are used, is adopted in formulating the LP for the furniture problem. That is the formulation is devoid of the value judgment of the Proprietor who is the decision maker. The generalized form of the conventional LP formulation (Sharma,2008) adopted is:

$$Optimize\ f(X) = CX$$

$$subjecto: AX = b$$
$$X \geq 0 \tag{1}$$

Where:

$C = (c_1, c_2 ..., c_n)$ are the coefficients of the decision variables in the objective function
$X = (x_1, x_2 ..., x_n)^T$ are the decision variables
$A = \lfloor a_{ij} \rfloor_{mxn}; i = 1,2,.., m; j = 1,2,..., n$ is matrix of the coefficients of the technological transformation of the Resources
$b = (b_1, b_2, ..., b_m)^T$ are the resources available for the transformation of the products.

The proposed approach incorporating the value judgment of the decision maker into the formulation was carried out as follows:

(1) Criteria which the decision maker uses in prioritizing the production of alternative decision variables were identified
(2) Saaty's 9-point scale was adopted in quantifying the verbal judgment of the relative importance of the criteria and the alternatives decision variables to each other
(3) Pairwise comparism matrices for the criteria and the alternative were developed
(4) Weights for ranking the criteria were derived from the pairwise matrix
(5) Weights for ranking the alternative decision variables were derived using the rankings of the criteria
(6) The weights for the alternatives decision variables were incorporated as coefficients of the decision variables in both the objective function and the constraints simultaneously.

Based on the rankings of the alternative decision variables, the proposed LP formulation, incorporating the value judgment of the decision maker, can generally be presented as follows:

$$Optimize\ f(X) = (C + \alpha)X$$

$$subjecto:(A+\alpha)X = b$$
$$X \geq 0$$
$$0 \leq \alpha \leq 1$$
$$\sum_{j=1}^{n} \alpha_i = 1 \qquad (2)$$

Where:

A, b, C and X are as defined in (1)

$\alpha = (\alpha_1, \alpha_2, ..., \alpha_n)$ are the rankings (priorityweights) of the alternative decision variables

The Case Study

Amazing Grace Furniture Company is a big Furniture Making Company that produces varieties of furniture for homes, offices and other use. The company is located in Yola the Adamawa State capital, Nigeria. The Proprietor of the company (decision maker) was interviewed to establish the procedure and policy of business operation. The interaction revealed that the company does not employ any scientific production scheduling strategy or policy but had the desire to have a scientific bases for scheduling production of the various furniture that will maximize profit and within the limited production resources.

Face to face value elicitation sessions were carried out with the decision maker as an enquiry to identify the criteria the Proprietor uses in judging the production of the furniture products.

Structured interview, in form of the Saaty's nine (9) point scale, was designed and administered to the Proprietor to obtain the relative importance of the criteria and the alternative furniture products.

Secondary data on the unit cost of production, unit selling price and unit quantity of raw materials needed were collected from the record of productions and sales of the company.

The LP Problem Formulation

(1) The traditional (conventional) formulation variables are defined as:

x_1 = number of units of 12 spring beds to be produced

x_2 = number of units of 10 spring beds to be produced

x_3 = number of units of wardrobes to be produced

x_4 = number of units of officetables to be produced

x_5 = number of units of officechairs to be produced

x_6 = number of units of upholsterychairs to be produced

s_j = sellingprice of one unit of furniture type j produced

c_j = cost price of producing one unit of furniture type, j produced

Estimated per unit cost and selling prices of the six furniture products were derived from the records of business transactions of the company. The estimates were used determine per unit profit for each furniture type produced . Since the objective (goal) of the company is to maximize profit arising from producing and selling the six different types of furniture, the objective function was formulated as:

$$\text{Maximise Total Profit} = \sum_{j=1}^{6} (s_j - c_j) x_j \qquad (3)$$

With the data collected, the objective function was formulated to be:

$$\textit{Maximize}: \text{Total Profit} = 30{,}000x_1 + 21{,}000x_2 + 10{,}000x_3 + 10{,}000x_4 + 3{,}000x_5 + 45{,}000x_6$$

The constraints were formulated as follows:

$$5x_1 + 4x_2 + 3x_3 + 3x_4 \leq 30 \text{ (3/4 MDF plywood)}$$
$$1.5x_1 + x_2 + x_3 + x_4 \leq 15 \text{ (1/4 MDF plywood)}$$
$$0.5x_1 + 0.5x_2 + 0.25x_3 + 0.25x_4 \leq 10 \text{ (hedges tape)}$$

$$0.5x_1 + 0.5x_2 + \qquad 0.5x_4 \le 15 \text{ (2 inches screw)}$$
$$0.5x_1 + 0.5x_2 \qquad \le 5 \text{ (1inches screw)}$$
$$x_1 + x_2 \qquad \le 5 \text{ (bed roll)}$$
$$x_1 + \quad x_2 + \quad x_3 \quad + 0.5x_5 \le 9 \text{(1 1/2 inch nail)}$$
$$x_1 + \quad x_2 \qquad \le 6 \text{ (floorbed)}$$
$$x_1 + \quad x_2 \qquad \le 4 \text{(mirror)}$$
$$4x_1 + 4x_2 + 2x_3 + 2x_4 \le 22 \text{ (14 inches roller)}$$
$$2x_1 + 2x_2 + 5x_3 \le 20 \text{ (cabinet inches)}$$
$$5x_1 + 5x_2 + 5x_3 + 2x_4 \le 35 \text{ (handles)}$$
$$4x_1 + 2x_2 + 2x_3 + 2x_4 + x_5 + 4x_6 \le 50 \text{ (gum/litres)}$$
$$0.5x_1 + \quad 0.5x_2 \qquad \le 3 \text{(sand paper)}$$
$$10x_1 + 10x_2 + 8x_3 + 8x_4 + 8x_5 + 10x_6 \le 1884 \text{ (time required/hours)}$$
$$15x_5 \qquad \le 40 \text{(planks)}$$
$$26x_6 \qquad \le 30 \text{(yards of cloth)}$$
$$x_5 + x_6 \qquad \le 5 \text{(rubber belt)}$$
$$16x_6 \qquad \le 20 \text{(iron legs)}$$
$$0.5x_6 \qquad \le 2 \text{ (6inches foam)}$$
$$0.5x_6 \qquad \le 2 \text{ (3inches foam)}$$
$$x_5 + 2x_6 \qquad \le 8 \text{(2inches foam)}$$
$$3x_6 \qquad \le 8 \text{ (1inch foam)}$$
$$x_6 \qquad \le 4 \text{ (0.5inch foam)}$$
$$4x_5 \qquad \le 15 \text{ (paint /litres)}$$
$$x_j \ge 0 \text{ and integer}; \forall j = 1, 2, \cdots, 6$$

(2) The proposed formulation

(a) Determining the priority weights for the decision variables, x_j relative importance of the criteria used to assess the productions of the alternative furniture products.

The Proprietor's hierarchy, depicting the goal, the identified criteria and the alternative furniture products is represented by Fig 1.

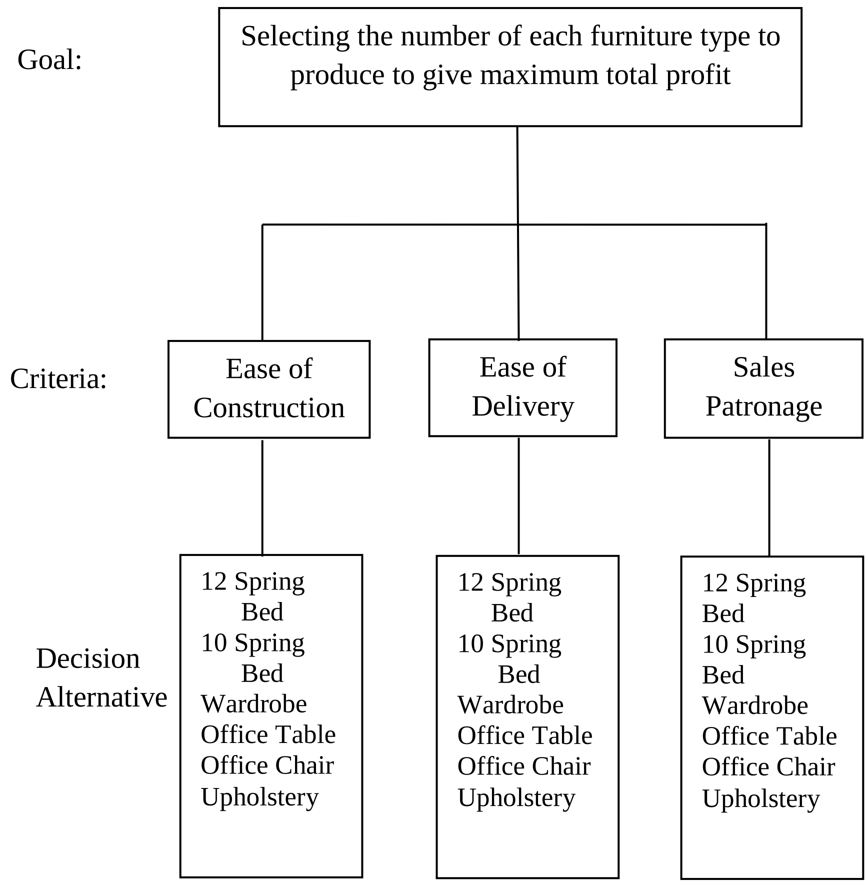

Fig1: The Analytic Hierarchy Process for the Furniture Production

(i) The priority rankings of the criteria

The verbal judgment of the relative importance of the criteria by the Proprietor was captured using the Saaty's nine (9) point scale. The numerical ratings obtained for the criteria were used to develop pairwise comparison matrix, from which the priority rankings of the relative importance of the criteria were derived, using Microsoft excel worksheet.

$$P_c = \begin{bmatrix} & c_1 & c_2 & c_3 \\ c_1 & 1 & 7 & 6 \\ c_2 & \frac{1}{7} & 1 & \frac{1}{3} \\ c_3 & \frac{1}{6} & 3 & 1 \end{bmatrix}$$

c_1, c_2, *and* c_3 represents ease of construction, ease of delivery, and sales patronage respectively

The priority ranking was derived from this matrix, R_c is:

$$R_c = \begin{bmatrix} 0.7394 \\ 0.0818 \\ 0.1788 \end{bmatrix}$$

This result indicates that ease of construction is the most important criterion (0.7394) the proprietor considers in producing the different furniture types. This followed sales patronage (0.1788) while the least important criterion is ease of delivery. The eigen vector method was employed to derive the matrix R since only one decision maker was encountered and thus resulting into the pairwise matrix exhibiting reciprocity property that

$$a_{ij} = \frac{1}{a_{ji}}. \qquad (4)$$

A consistency ratio of 0.10 or less is considered acceptable. In as much as the pairwise comparison for the decision maker criteria shows CR = 0.0882, we can conclude and state that the degree of consistency in the pairwise comparisons is acceptable, hence the decision maker(s) verbal judgments are acceptable.

(ii) The priority rankings of the alternative furniture products against the criteria

The verbal judgment of the relative importance of the alternative furniture products aginst each of the criteria by the Proprietor was captured using the Saaty's nine (9) point scale. The numerical ratings obtained for the alternative furniture products were used to develop Pairwise comparison matrix associated with each of the three criteria. Priority rankings of the relative importance of the alternative furniture products against each criteria were derived, using Microsoft excel worksheet. The results are as follows:

	x_1	x_2	x_3	x_4	x_5	x_6
x_1	1	1	5	3	3	5
x_2	1	1	3	3	3	5
x_3	1/5	1/3	1	3	1/3	4
x_4	1/3	1/3	1/3	1	1/2	5
x_5	1/3	1/3	3	2	1	3
x_6	1/5	1/5	¼	1/5	1/3	1

Pairwise Comparison Matrix of Alternative furniture products on Ease of Construction

This results into the following priority rankings:

$$R_{xc_1} = \begin{bmatrix} 0.3111 \\ 0.2846 \\ 0.1182 \\ 0.1000 \\ 0.1447 \\ 0.0414 \end{bmatrix}$$

The consistency ratio (CR) of this Pairwise matrix was obtained as 0.0987, indicating consistency the verbal judgment of the alternatives against the ease of construction as a criterion.

	x_1	x_2	x_3	x_4	x_5	x_6
x_1	1	1	2	5	5	5
x_2	1	1	2	5	5	3
x_3	½	½	1	5	5	3
x_4	1/5	1/5	1/5	1	1	2
x_5	1/5	1/5	1/5	1	1	¼
x_6	1/5	1/3	1/3	½	4	1

Pairwise Comparison Matrix on Alternative furniture products on ease of Delivery.

The rankings of the alternative furniture products against the ease of delivery were obtained as:

$$R_{xc_2} = \begin{bmatrix} 0.3092 \\ 0.2858 \\ 0.2041 \\ 0.0677 \\ 0.0473 \\ 0.0858 \end{bmatrix}$$

The CR of 0.0681, was obtained for this matrix and the verbal judgment was also consistent

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Similarly, the Pairwise matrix on the sales patronage was obtained as:

	x_1	x_2	x_3	x_4	x_5	x_6
x_1	1	1	3	5	5	3
x_2	1	1	3	5	5	4
x_3	1/3	1/3	1	5	5	1/3
x_4	1/5	1/5	1/5	1	1	1/5
x_5	1/5	1/5	1/5	1	1	1/5
x_6	1/3	¼	3	5	5	1

The rankings of the alternative furniture products against the sales patronage were obtained as:

$$R_{xc_3} = \begin{bmatrix} 0.2913 \\ 0.3104 \\ 0.1349 \\ 0.0442 \\ 0.0442 \\ 0.1750 \end{bmatrix}$$

The CR of 0.0801, was obtained for this matrix and the verbal judgment indicating that the verbal judgment of the decision maker on this was equally consistent.

(iii) **The overall priority ranking of the alternative furniture products**

The overall priority ranking for the alternative furniture products were computed as:

$$R_x = R_c.R_{xc_i} \tag{5}$$

$$R_x = \begin{bmatrix} 0.3074 \\ 0.2893 \\ 0.1282 \\ 0.0874 \\ 0.1188 \\ 0.0689 \end{bmatrix}$$

The results indicate that the Proprietor ranks the production the productions of the alternative furniture products as follows:

Decision Maker's Priority Ranking Output

Rank	Decision Alternatives	Priority
1	x_1	0.3074
2	x_2	0.2893
3	x_3	0.1282
4	x_5	0.1188
5	x_4	0.0874
	x_6	0.0689

(b) Incorporating the Priority Rankings of the Alternative Furniture Products into the LP Formulation.

The LP, incorporating the priority ranking of the alternative furniture products, was formulated as follows:

$$Maximize\,profit = 30{,}000.3074x_1 + 21{,}000.2893x_2 + 10{,}000.1282x_3 + 10{,}000.0874x_4 + 3{,}000.1188x_5 + 45{,}000.0689x_6$$

$Subject\,to:$

$5.3074x_1 + 4.2893x_2 + 3.1282x_3 + 3.0874x_4 \le 30$ (3/4 MDF plywood)

$1.8074x_1 + 1.2893x_2 + 1.1282x_3 + 1.0874x_4 \le 15$ (1/4MDFplywood)

$0.8074x_1 + 0.7893x_2 + 0.3782x_3 + 0.3374x_4 \le 10$ (hedges tape)

$0.8074x_1 + 0.7893x_2 + \quad + 0.3374x_4 \le 15$ (2inchesscrew)

$0.8074x_1 + 0.7893x_2 \le 5$ (1inch screw)

$1.3074x_1 + 1.2893x_2 \le 5$ (bed roll)

$1.3074x_1 + 1.2893x_2 + 1.1282x_3 + 0.6188x_5 \le 9$ (1 1/2 nail)

$1.3074x_1 + 1.2893x_2 \le 6$ (floorbed)

$1.3074x_1 + 1.2893x_2 \le 4$ (mirror)

$4.3074x_1 + 4.2893x_2 + 2.1282x_3 + 2.0874x_4 \le 22$ (14inches roller)

$2.3074x_1 + 2.2893x_2 + 5.1282x_3 \le 20$ (cabinet inches)

$5.3074x_1 + 5.2893x_2 + 5.1282x_3 + 2.0874x_4 \le 35$ (handles)

$4.3074x_1 + 2.2893x_2 + 2.1282x_3 + 2.0874x_4 + 1.1188x_5 + 4.0689x_6 \le 50$ (gum/litres)

$0.8074x_1 + 0.7893x_2 \le 3$ (sand paper)

$10.3074x_1 + 10.2893x_2 + 8.1282x_3 + 8..0874x_4 + 8.1188x_5 + 10.0689x_6 \le 1884$ (time required/hours)

$15.1188x_5 \le 40$ (planks)

$26.0689x_6 \le 30$ (yards of cloth)

$1.1188x_5 + 1.0689x_6 \le 5$ (rubber belt)

$16.0689x_6 \le 20$ (ironlegs)

$0.5689x_6 \le 2$ (6inches foam)

$0.5689x_6 \le 2$ (3inches foam)

$1.1188x_5 + 2.0689x_6 \le 8$ (2inches foam)

$3.0689x_6 \le 8$ (1inch foam)

$1.0689x_6 \le 4$ (0.5inches foam)

$4.0689x_5 \le 15$ (paint/litres)

$x_i \ge 0$ and integer; $\forall\, i = 1, 2, \cdots, 6$

Table 2: Summary of the Optimum solutions for the Conventional LP and AHP-LP formulations and the monthly average production schedule

Furniture product	Average monthly production	Conventional LP Solution	Proposed LP-AHP Solution
x_1	2	4	3
x_2	1	0	0
x_3	2	2	2
x_4	2	1	2
x_5	1	2	2
x_6	1	1	1
Maximum Net Profit		NGN201000:00	NGN181001.70

3. DISCUSSION OF RESULTS

The results of the LPs formulated were derived using TORA software. Optimum solutions for the conventional ("traditional") LP formulation and that involving the decision maker's value judgment (LP-AHP) were obtained as integer solutions. The optimum results were compared with the monthly average production derived from the company's record of business transactions.

The optimum solutions from the conventional LP formulation indicate the following monthly production schedules: 4 units of 12 spring beds (x_1), no (0) unit of 10 spring beds (x_2), 2 units of wardrobes (x_3) , 1 unit of office tables (x_4), 2 units of office chairs (x_5) with 1 unit of upholstery chair (x_6). This monthly production schedule will result into a maximum net profit of NGN201,000.00 per month.

The optimum solutions resulting from the AHP-LP formulation indicate the following monthly production schedules: 3 units of 12 spring beds (x_1), no unit of 10 spring beds (x_2) , 2 units of wardrobes (x_3), 2 units of office tables (x_4) , 2 units of office chairs (x_5) with 1 unit of upholstery chairs (x_6). This production schedule will result into a maximum net profit of NGN181,001.70 per month.

Average number of each furniture product type was computed from four years records of business transactions of the company which indicate that 2 units of 12 spring beds 1 unit of 10 spring bed, 3 units of wardrobes , 2 units of office tables, 1 unit of office chairs with 1 unit of upholstery chair. This intuitive production schedule resulted an average net profit of NGN170,974.50 per month.

Comparing the results obtained this problem, it can be inferred that the deviations of optimal solutions derived from LP-AHP based formulation to the average monthly production schedule are minimal whereas the optimal solutions derived from the conventional LP formulation to the average monthly production schedules are relatively significant. In fact the deviation of the maximum net profit from the LP-AHP formulation is NGN10,027.20 (NGN181,001.70- NGN170,974.50) while it is NGN30,025.50 (NGN201,000.00 - NGN170,974.50). Based on outcome of these analyses, we suggest that the value judgment of a decision maker needs to can be quantified, in terms of weight that prioritized the decision variables, using AHP and incorporated into an LP formulation. This will give more realistic optimum solutions to an LP problem.

4. CONCLUSION

This study utilized both the quantitative secondary and the qualitative data for formulating a more realistic LP that incorporates the value judgment of a decision maker.
Thus, an LP problem formulation was proposed with the priority rankings(weights), using AHP, of the decision variables and incorporated as additional information for determining the coefficients of the variables of the decision variables in both the objective function and the constraints. The optimum solutions derived from the proposed model formulation thus suggest that the decision maker's value judgment should be incorporated into the formulation of the LP problem.

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