

Knowledge-Graded Manpower Planning Model for the Manufacturing Industry

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Abstract: In developing the model, knowledge levels of workers which were categorized as unskilled, semi- skilled and skilled with their respective production capabilities were first identified. A linear programming (LP) – model was formulated based on the aforementioned knowledge levels with the inclusion of variables such as productivity of workers, product demand, cost of hiring of manpower, training cost of manpower, and the number of available workers at different stages of knowledge development in knowledge intensive operations. The model was also extended to the management of knowledge mix of workers in different knowledge levels which was used in determining quantity of workers at each level that sustained expected production target(s). The movement of manpower from one knowledge grade to another was achieved through training, and /or knowledge acquisition. The model was applied to agricultural equipment manufacturing company based in Lokoja, Nigeria. The outcomes of the new scheme were compared with the conventional approach formerly used in the Company. The results obtained from the developed scheme showed substantial savings both in cost and number of unskilled, semi skilled and skilled manpower in the company. The model formulated is very appropriate for meeting manpower needs of developing economy such as Nigeria.

Key-Words: *Human Resource Planning; Knowledge Intensive Operation; Manufacturing; Control.*

1. Introduction

Planning for people becomes important when job requirements specify scarce skills and capabilities [1]. Qualified and skilled people have become scarce, and human resource planning has become a necessity for long – term survival in industrial economy [2]. Human resource needs planning to meet business objectives and gain advantage over competitors [3]. Manpower planning is getting the right number of people (by personnel or line manager) with the right skills, experiences, and competencies in the right job at the right time [4-7]. Knowledge intensive operations are characterized by extensive knowledge required for each worker. Those who complete the training program, find themselves valuable to other companies that can take

advantage of the knowledge acquired by this group of workers, and therefore leave for better opportunities [8]. In recent time human resource managers have placed emphasis on control of employee attitudes, feelings and commitment [9-12]. The situations in many public sectors and private organizations in the country are such that no conscious efforts have been made on the quantitative determination of manpower requirement to their advantage. The consequences of inadequate manpower planning include imbalance recruitments, promotion and unnecessary sack of employee that might lead to unsatisfactory performance of the system in the long run. It is pertinent to mention here that earliest attempt to forecast a classed population was made by [13,18]. But [14, 35] developed a Markovian model to predict proportions of workers in each grade of the manpower stock. Authors like

[15] had developed an analytic method while [16,17] used linear programming approach. A myriad of human resource planning problems were addressed in literature, but not many of them are directly related to hiring and training decisions in knowledge based operation with stochastic turnover rate [19-24, 27]. Little literature that dealt with learning aspect [9, 17, 25-33], failed to address the issue of how personnel can be graded based on the levels of knowledge and training acquisition. This model is different from aforementioned models by taking into account training program, progress and recruitment schedule at every worker level.

2. Method

The methodology adopted includes model development, testing and validation with a case study.

2.1 Model Development

In the current, highly uncertain socio- economic climate, the human resource planning function is emerging as a focal human resource activity as it is increasingly becoming an essential and very prominent function. As such, that function endorses the crucial role of dealing with the necessary changes in the volume and make-up of the workforce. There is need for manpower planning to deal with changes in work force requirement under stochastic conditions. Therefore, a model for manpower planning under uncertain conditions was developed and validated. The various procedures involved in the model developments included model formulation, model validation, and solution procedure.

2.2 Model Formulation

The model is a discrete time model in which knowledge levels of workers, $i = 1, 2, 3 \dots n$ and production stages A, B... N in a production line is prescribed. All new hires always start in stage A and undergo on-the-job training in stage A during the first period. This is knowledge level 1 and the number of workers at time t in knowledge level 1 is denoted as $X(t)$. When training in the first stage is completed for a group of new hires, they are assigned to stage B in the next period, where they undergo training in this stage, this is knowledge level 2 and the number of workers at this level at time t is

denoted by $W_2(t)$. After a worker has completed training at both A, B, ..., N stages (where N is the maximum number of production stages) the worker is promoted to knowledge level 3 and n respectively. The number of workers at time t at this level is denoted as $W_3(t)$ and at knowledge level n as $W_n(t)$ respectively. This worker assignment scheme is indicated in Figure 1.

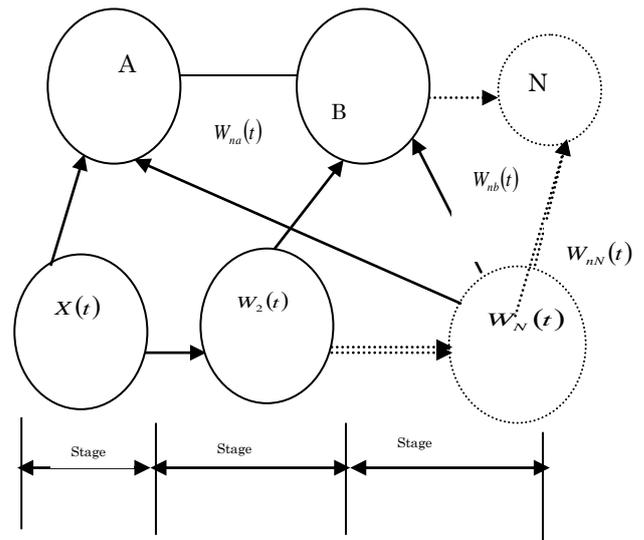


Figure 1 Production stages and worker knowledge levels

All new employees go through this career path to gain integrated knowledge on the production at both stages. Since workers at stage B are expected to check the quality of work done at the preceding stage A, new hires must be trained first at stage A. Therefore, the new hires who have completed training at stage A are immediately assigned to stage B because the workers at stage A should know the succeeding operations at stage B to enhance quality. While it may be possible to hire a worker at intermediate level, this was not included in the model but it will be considered later, because the emphasis now is on skill building practice of knowledge workers. Since this is a knowledge intensive operation, the minimum amount of training necessary for the workers who have some experience in similar settings in other operations is large enough to warrant a complete training program. Moreover, the availability of such workers may be limited.

Some level 3 workers are assigned to training level 1 and

level 2 workers on the job. These level 3 workers who are used for training new or newly promoted workers are not contributing to the production of the plant. Depending upon the demand requirement and productivity of workers in knowledge levels 2 and 3, the necessary numbers of workers from knowledge level 3 were assigned to stage B (denoted by $W_{3b}(t)$) in Figure 1.

The remaining numbers of workers from knowledge level 3, after adjusting for trainers at stage B are assigned to stage A (denoted by $W_{3a}(t)$) in Figure 1). Thus, depending upon the demand requirements and productivity of workers in knowledge levels 1 and 3, the number to be hired in level 1 is determined. It is planned that all workers in knowledge level 2 are to be assigned to stage B. This is done by design in the skill building practice in order to keep the workers motivated and enhance quality.

Let q_1 and q_2 denote the training fraction for level 1 and 2 workers respectively.

That is, $q_1 X(t)$ of level 3 workers are used to train level 1 workers in period t. Similarly $q_2 W_2(t)$ of level 3 workers are used to train level 2 workers in period t. Hence, the following inequalities must be satisfied Workers training constraint for level one worker

$$W_{3a}(t) \geq q_1 X(t) \tag{1}$$

Workers training constraint for level two worker

$$W_{3b}(t) \geq q_2 W_2(t) \tag{2}$$

The demand for the product is denoted as $d(t)$ which is an independent, identically distributed random variable independent of $X(t)$ and $W_i(t)$, $i = 1,2,3 \dots n$, where n is the maximum knowledge level ,it is also assume that no single worker will be assigned to both stages A and B on partial assignment basis.

The productivity of workers at knowledge level i is denoted as P_i for $i = 1, 2, 3 \dots n$. Since group 3 is fully trained in both the stages, its productivity will be higher than that of knowledge groups 1 and 2 (i.e $P_1 \leq P_3$ and $P_2 \leq P_3$. The objective is to minimize the total worker related costs for which it is aimed at meeting demand by employing the

optimal number of workers at different levels. The assignment of workers was started by fulfilling the needs for stage B first. Firstly, all level 2 workers – level 1 in previous period was assigned – to stage B. Then, based on the demand requirement and after adjusting for the training needs for level 2 workers at stage B, the necessary number of level 3 workers was assigned to stage B. Therefore, the production function at stage B would be

$$P_2 W_2(t) + P_3 (W_{3b}(t) - q_2 W_2(t)) = d(t) \tag{3}$$

Next, the assignment for stage A. Firstly, all remaining workers from level 3 was assigned to stage A. If there is insufficient number of workers to meet demand, there is need to recruit new workers. While deciding the number of new recruits, we must also keep in mind the requirement of level 3 workers to train the new workers who will not be contributing to the production. Therefore, the production function at stage A becomes

$$P_1 X(t) + P_3 (W_{3a}(t) - q_1 X(t)) \geq d(t) \tag{4}$$

The worker balance equation for level 3 workers is

$$W_3(t) = W_{3a} + W_{3b}(t) \tag{5}$$

The non- negativity conditions are

$$X(t), W_2(t), W_{3a}(t), W_{3b}(t) \geq 0 \tag{6}$$

Summary of equations (1) - (6) are equivalent to the equations (7) - (10) that do not include,

$$W_{3a}(t) \text{ and } W_{3b}(t)$$

Production function demand constraint at stage A

$$(P_1 - P_3 q_1) X(t) + (P_2 - P_3 q_2) W_2(t) + P_3 W_3(t) \geq 2d(t) \tag{7}$$

Production demand constraint for level two worker

$$P_2 W_2(t) \leq d(t) \tag{8}$$

Production function demand constraint at stage B

$$- P_3 q_1 X(t) + (P_2 - P_3 q_2) W_2(t) + P_3 W_3(t) \geq d(t) \tag{9}$$

Non –negativity constraints

$$X(t), W_2(t), W_3(t) \geq 0 \tag{10}$$

The progression of workers along the knowledge levels is shown in Figure 2. The retention rates (complement of turnover rates) at the knowledge levels are denoted as y_i for $i = 1,2$ and $3 \dots n$ and are defined as the probability that a worker at knowledge level i will stay in the

plant after a particular period. This are estimated based on historical data. After period 1, a proportion $1 - y_1$ of level 1 workers will on the average leave the system.

Let $Z_1(t)$ to denote remaining workers at the end of the period, who becomes level 2 workers in the next period and move to stage B. After period 2, a proportion $1 - y_2$ of level 2 workers will on average leave the system and the remainder (denoted by $Z_2(t)$ will become part of level 3 worker) After period 3, a proportion $1 - y_3$ will on the average leave the system and the remainder (denoted by $Z_3(t)$ will stay in the system). And after a period K a proportion of $1 - y_n$ will on the average leave the system and the remainder (denoted by $Z_n(t)$ will stay in the system). It is necessary to assume $y_3 < 1$ to attain a steady - state condition. The y_i 's are estimated based on historical data.

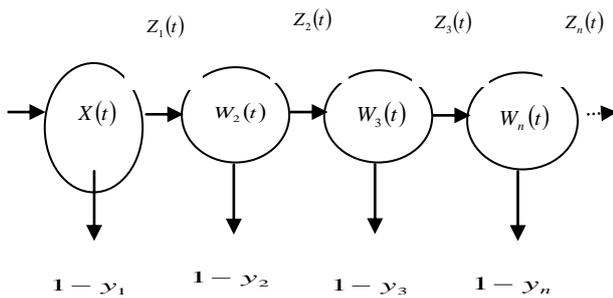


Figure 2 Flow of workers through knowledge levels

A hiring policy is developed in line with [32] in which relationship between the steady state levels of workers at different knowledge levels was established. First, the target levels are set

W_2^*, W_3^* and W_n^* for $X(t), W_2(t), W_3(t)$ and $W_n(t)$ respectively.

The following constraint relationship is set between the target levels:

$$W_2^* = y_1 X^* \tag{11}$$

$$W_3^* = y_2 W_2^* \tag{12}$$

The target level for level n workers is given as:

$$W_n^* = y_i W_i^* \tag{13}$$

Let ρ denote a restoration factor for $0 \leq \rho \leq 1$.

This restoration factor indicates the extent to which the gap between the target workforce and current workforce in the subsequent levels is affecting the decision on the recruitment level at level 1 in the very next period [34,35]. A value of $\rho = 0$ indicates that we disregard the gap between the current and target workforce in the upstream levels while hiring for level 1. A value of $\rho = 1$ indicates that we allow the complete gap to effecting hiring decision.

Therefore using the concepts of restoration factor and target values introduced in [36-39] (which is also called the proportional control in the control theory literature), the following linear control rule is therefore introduced

$$X(t) = X^*(t) + \rho(W_2^*(t) - W_2(t)) + \rho(W_3^*(t) - W_3(t)) + \dots + \rho(W_n^*(t) - W_n(t)) \tag{14}$$

Equation (14) is the decision rule. The decision rule implies that, at the beginning of every period, the required number of workers to be hired in knowledge level 1, $X(t)$, would be calculated using equation (14). This decision with the turnover rates at all knowledge levels at the end of that period, will determine the work force levels at next two knowledge levels in the beginning of next period. Under normal condition based on the initial assumption the decision makers in the company are not suppose to hire workers directly to level 2 or any other level of the knowledge workers as a result of skill building practice of knowledge workers.

From equation (14) we can see that the number of workers at a knowledge level is adjusted every period depending upon a number of factors, namely the turnover rates, the restoration factor, the target worker levels and current worker levels. This equation takes into consideration the uncertainty in turnover rates and regulates the number of workers at each knowledge level. The following worker related cost parameters are used for deriving the objective function.

C_i :Wage of a worker in knowledge level i , for $i = 1, 2, 3..$

T_i : Training cost of one worker in level i , for $i = 1, 2$ and $3..n$

The focus is on long term work force planning of knowledge worker for which the above cost are relevant.

The overtime cost was not included in the model since it is considered to be a short-term correction. Then, the objective function is

$$Min(c_1 + h_1 + r_1)X(t) + (c_2 + r_2)W_2(t) + \dots + (c_i + r_i)W_i + (c_n W_n(t)) \quad (15)$$

Subject to the constraints equations given previously as equations (7)-(10)

Productivity of labour as pointed out by [35,36] is given as

$$Productivity\ of\ labour\ P_i = \frac{\sum_1^n TP}{\sum_1^n TO} \quad (16)$$

$\sum_1^n TP$ is Total Production/day of a skill level ,

$n = 1,2,\dots$, and $\sum_1^n TO$ is Total number of Operators or workers of a skill level , $n = 1,2,\dots$

2.3 Solution Procedure

The solution processes for determination of optimum number of workers is given as:

Total Training Cost:

$$\sum TC = n_1 r_1 + n_2 r_2 + \dots n_i r_i \quad (17)$$

Where $\sum TC$ is Total Training Cost, $n_1, n_2 \dots n_i$ is number of level one, level two workers hired to level i , and r_i is Training cost of one worker in level $i = 1,2,3,\dots n$

2.4 Model Validation

Data were collected from an agricultural equipment manufacturing company based in Lokoja, Nigeria. The company performs assembly line operations for cassava grater, palm oil extractor, seed planter, rice transplanter, fertilizer sprayer, and rice husker. The assembly operations are categorized according to their complexity as “Simple build” or “Complex build” – operations. A new worker is normally assigned to the simplest of the operations among the “simple build” stages, which is generally the first operation. Training is mostly on the job: in the form of initial observation;

teaming up with experienced workers; and last, solo responsibility. The worker knowledge levels are measured by the type of unit of products that they can assemble with respect to time. A unit is a complete assembly of product e.g. a seed planter is a unit. The main issues in the staffing decisions are twofold: to determine how many workers to hire at the beginning of each period; and to develop an appropriate training schedule for higher productivity and flexibility.

The cycle time of the plant is 60 minutes, which means that a worker needs to learn 60 minutes worth of work content in a work station. A worker takes 52 weeks to complete training in either of stages A and B. The training schedule is such that each worker will be ready to move from simple build stations to complex build stations in 52 weeks. A period as applied to the formulation will be length of 52 weeks. Therefore, Cycle time is 60 minutes, a period is 52 weeks and shift length is 8hrs.

The data for the product demand in units for each thirteen weeks of a quarter of a year was collected. The production for eight hour shift per day was calculated for each year by dividing the total production in units for each year with total number of weeks of the year (52 weeks) and number of production days per week (5 in this case) , the resulting data is shown in Table 1. The wages, hiring cost C_i and training cost I_i for three knowledge levels per worker per year was collected and is shown in Table 2. Naira ₦, is the symbol of Nigeria Currency (1 USD is equals to N150). The data for number of workers for each knowledge level per year and number of workers that was engaged in training was collected and the training fractions was computed by dividing the number of workers that was engaged in training for each level with the total number of worker at respective level for each year. The resulting data is shown in Table 3. Workers states at the company between 2004 to 2006 which include the number of workers employed, number of workers that left the company and number that was promoted was collected and

shown in Table 4.

Table 1 Demand level per units of product at the plant for each 52 weeks and production for eight hour shift per day

Quarter (wks)/year		Demand (in Units)		
		2004	2005	2006
1st	13	504	510	509
2 nd	13	502	508	507
3 rd	13	506	502	505
4 th	13	508	520	531
$d(t)$ (prod. Capacity)	Total	2020	2040	2052
	\bar{x} (mean)	505	510	513
Eight hour shift		7.77	7.85	7.89

Table 2 Wages and Training cost for the three knowledge levels

i (knowledge level)	1	2	3
c_i ₦/year/ worker	216,000	360,000	540,000
t_i /worker/yr	4,000	4,500	-

Table 3 Number of workers and their training fraction for three years

i (knowledge level)	1	2	3	Years
W_i (Number of workers)	9	6	17	2004
	7	5	8	2005
	8	6	10	2006
Number of level i workers engage in Training	4	2	-	2004
	3	2	-	2005
	4	3	-	2006
Training fraction q_i	44%	33%	-	2004
	43%	40%	-	2005
	50%	50%	-	2006

The data for total contribution of each knowledge level worker to revenue generated by the company for each month was collected for each year. The mean was then computed for each level per year, the resulting output is shown in Table 5.

Table 4 Workers Status at the plant from 2004 to 2006

year	2004			2005			2006		
Knowledge level i	1	2	3	1	2	3	1	2	3
Number of workers employed:	9	6	17	0	0	0	3	1	1
Number of workers that left:	0	0	0	2	1	6	1	2	1
Number promoted:	0	0	0	2	1	-	3	2	-

Table 5 Contribution of Each Knowledge Level Worker in Millions Naira to Revenue Generated By the Plant

	Years	Tota	Years	Total	Years	Tota
	2004	1	2005		2006	1
Knowledge level	1 2 3		1 2 3		1 2 3	
Month	X10 ⁶		X10 ⁶		X10 ⁶	
1	5 6 9	20	6 8 10	24	6 8 11	25
2	6 7 10	23	6 8 10	24	6 8 11	25
3	4 5 8	17	5 7 11	23	6 8 11	25
4	4 5 8	17	5 7 11	23	5 8 11	24
5	6 7 10	23	6 8 10	24	7 10 12	29
6	5 6 9	20	7 8 11	26	7 10 12	29
7	5 6 9	20	6 8 10	24	5 8 11	24
8	5 6 9	20	6 8 10	24	5 8 11	24
9	6 7 10	23	5 7 11	24	5 8 11	24
10	6 7 10	23	4 6 9	19	6 9 12	27
11	6 7 10	23	5 7 11	23	6 9 12	27
12	6 7 10	23	5 7 11	23	7 10 13	30
Average	5.3,6.3,9.3	21.0	5.5,7.4,10.4	23.41	5.9,8.6,11.5	26.1

The productivity of labour for each knowledge level in units of product produced per shifts of 8hrs/day was calculated using equation (37) and data in Tables 1, 3 and 4. The productivity for fifty two (52) weeks was then computed by multiplying the productivity per shift of 8hrs/day by number of production days (5 in this case) and number of production weeks (52) for each year considered. The resulting

computation results are shown in Table 6. Retention rates (y_i) which is the probability that a worker at knowledge level i will stay in the company after a particular period as shown in Figure. 2 is computed by subtracting the probability of workers at any knowledge level leaving the company from one (i.e. Probability of staying = 1 – Probability of leaving). The resulting computation is shown in Table 7.

Table 6 Productivity of the three knowledge level in units of product produced

i (knowledge level)	1	2	3	year
P_i (Productivity of each worker per shift of 8hrs/day)	0.86	1.3	0.56	2004
	1.12	1.57	0.98	2005
	0.99	1.32	0.79	2006
P_i for 52 weeks (in units)	224	338	146	2004
	291	408	255	2005
	257	343	205	2006

Table 7 Retention rate of worker from one knowledge level to another between 2004- 2006

Knowledge level i	1	2	3	Year
y_i	0.77	0.83	0.57	2004-2005
	0.88	0.67	0.9	2005-2006

in 2006, number of level one workers hired (n_1) is 3 , Number of level two workers hired (n_2) is 1 and number of level 3 workers hired (n_3) = 1

Also from Table 2, hiring cost (h_i)/worker is ₦6000, training cost per worker for level one worker (r_1) is ₦4000 and Training cost per worker for level two workers (r_2) is ₦4, 500.

Total training cost is calculated using equation (17) thus:

$$\sum TC = \text{₦}16, 500$$

Therefore, the objective function and constraints are developed based on equations (1)-(10) as

$$Z = \text{Min}[226000X(t) + 364500W_2(t) + 540000W_3(t)]$$

Subject to

$$154.5X(t) + 240.5W_2(t) + 205W_3(t) \geq 4050$$

$$343W_2(t) \leq 2052$$

$$-102.5X(t) + 240.5W_2(t) + 205W_3(t) \geq 20 \cdot 02$$

$$X(t), W_2(t), W_3(t) \geq 0 \text{ and integer}$$

Equations reduce to

$$X(t) + 1.56W_2(t) + 1.33W_3(t) \geq 26.21$$

$$W_2(t) \leq 6$$

$$-X(t) + 2.35W_2(t) + 2W_3(t) \geq 20.02$$

$$X(t), W_2(t), W_3(t) \geq 0 \text{ and integer}$$

The optimum solution was determined by using the branch-and-bound method of integer programming [40] and it is represented in Figure 6.

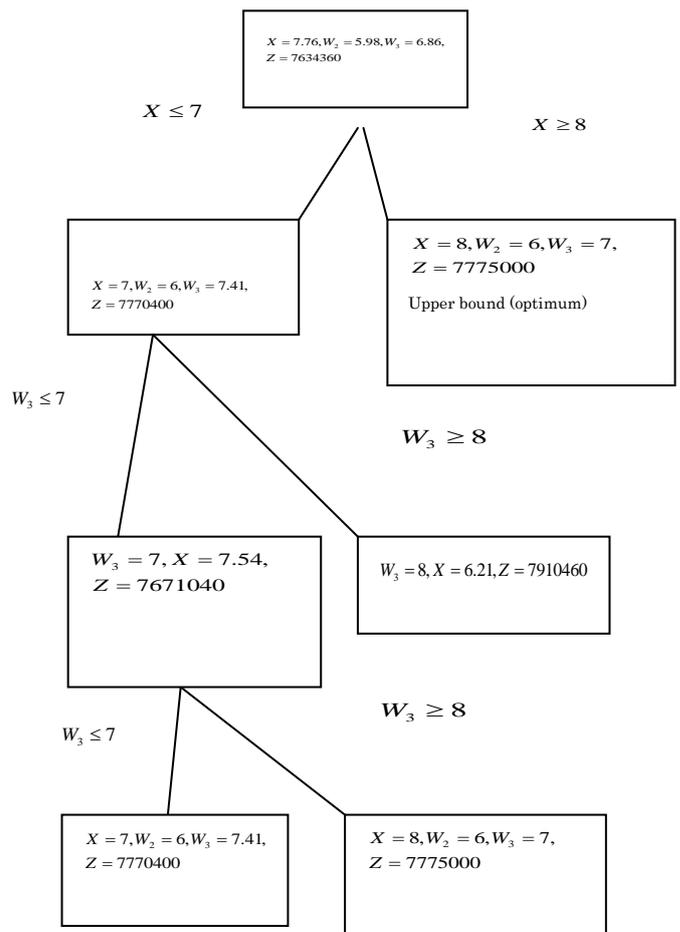


Figure 6 Determination of the optimum solution using Integer programming

The optimum solution is therefore

$$X(t) = 8, W_2(t) = 6, W_3(t) = 7, \\ Z = 7775000$$

Similar procedure was used to evaluate the system for years 2004 and 2006 using data in Tables 2 and 4, respectively.

3. Result and Discussion

The results of the optimum number of workers at each level and the cost implication is shown in Table 8 using simplex method [40]. The optimal numbers of workers were found to be 9.07 for level one worker, 5.98 for level two workers and 7.67 for level three workers at the total cost of ₦8,371,804.60. In order to eliminate fractional estimate of manpower, the optimal numbers of manpower through integer programming approach were 8, 6 and 7, respectively, with attendant total cost of ₦7,775,000. This outcome from integer programming showed improvement over the use of fractional based simplex method. The optimum manpower requirement and cost of manpower for the industry that was obtained based on the developed integer programming based model are summarized in Table 9 for the years 2004, 2005, and 2006, respectively. The outcomes generally showed a manpower cost reduction over the use of simplex approach.

Table 8 Manpower requirement based on the model for 2004

Workers level	Simplex method	Integer programming
1	9.07	8
2	5.98	6
3	7.67	7
Z(cost)	₦8,371,804.60	₦7,775,000

If the outcomes from the model in Table 9 are compared with what were obtainable in the company as shown in Table 10, it can be deduced that the cost of operating the manpower was considerably high as compared to the outcomes from the new scheme. Explicitly, the results in Tables 9 and 10 show that in 2004 the current worker ratio 9:6:17 for level one, two and three, respectively with labour cost of ₦13,401,000 is expensive compared with the model calculated results of 8:6:7 for level one, two and three, respectively with labour

cost of ₦7,775,000. The industry over-estimated the number of workers for the levels. Similar situation was found from the outcomes of 2005 and 2006 as shown in the table. Therefore, the results showed a mismatch in manpower requirement and utilization in the industry which must have contributed to high cost of production.

Table 9 Optimum Manpower Requirements and Cost of Manpower from 2004 to 2006

Manpower/year	2004	2005	2006
Level one	8	7	8
Level two	6	5	6
Level three	7	5	7
Total	21	17	21
Cost (Z)	₦7,775,000	₦6,104,500	₦7,775,000

Table 10 Manpower Utilization and Cost of Manpower from 2004 to 2006

Manpower/year	2004	2005	2006
Level one	9	7	6
Level two	6	7	4
Level three	17	12	12
Total	32	26	22
Cost(Z)	₦13,401,000	₦10,613,500	₦9,254,000

4. Conclusion

The Linear programming (LP) - model was developed for determining the optimum number of workers at each knowledge levels for the industrial case study, with the objective function of minimizing worker related cost and also meeting demand with the required level of reliability. The various procedures involve in the model developments include model formulation, model validation.

In the development, management of knowledge mix, workers in different knowledge levels such as unskilled (level one), semi- skilled (level two) and skilled levels (level three) was focused. Based on these levels, series of models were formulated was based on direct recruitment of manpower

into first level only, and the movement of manpower from one knowledge level to another based on training and knowledge acquisition. Production and labour data were collected from the agricultural equipment manufacturing company, Lokoja, Nigeria based on the parameters of the model and that data after analysis were used to test the model. The application of the model showed that the optimal mix of workers at different knowledge levels was quite different from the previously applied conventional method in the plant. As a result of this, there is need for reduction in number of workers that are currently engaged by the company to reduce the labour cost.

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