Optimal Redesign of the Organisation Structure of a Steam Power Plant

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Abstract

The purpose for which an organisation is established usually determines how the organisation will be set up in terms of office space, plant requirement and layout (if any), organisation structure, management philosophy to mention a few. This research was carried out to apply established quantitative methods to the redesign and optimisation of the organisation structure of a steam power plant. This is in dissonance with usual empirical strategies that were deployed in the past. The existing organisation structure was examined in light of the work content. This was used to estimate the number of operation level personnel (N0) and the human dynamic interactions rate (λ, μ). These estimates were then used to solve and maximise the personnel utilisation objective function (H). It was a non-linear constraint maximisation problem. The organisation's operating labour man-hours was found to be 98285.149 and the operation level personnel (N0) was found to be 135 persons supervised and managed by 14 and 5 persons respectively. After optimisation, the redesigned organisation structure had a personnel utilisation of 97.91% and a personnel cost saving of 49.6% which led to the conclusion that the redesigned structure outperformed the existing structure.

Keywords
Organisation structure, Personnel utilisation, Optimisation, Management levels.

1. Introduction
Organisational structure exists in various forms across various industries. Charles-Owaba (2002) describes it as the acceptable working relationship of employees towards the achievement of the primary goal of the establishment. The level of productivity of production firms is heavily dependent on applied exact science such as; operations design, process design, facility design among others. However, until recently, little attention has been given to the use of quantitative methods to analyse the exact number of workers required to successfully run an organisation. The irony of this is that the design of organisational structures has been studied scholastically for over 100 years with few scholars taking the study to a quantitative level.

This research builds on the works completed by Charles-owaba (2002) and Hax and Majiluf (1981) in making a case and establishing a quantitative method for the design of the organisational structure of a company using the operation research paradigm. Akindele (2019) and Ini (2019) have tested this method by successfully optimising the organisational structure of a hospital and a manufacturing plant respectively.

1.1 Statement of the Problem
The ownership of steam power was recently transferred from the government sector to private hands as part of efforts by the government to revitalise the power industry. While there is an emphasis on productivity, there is also a

requirement of holistic efficiency to ensure the profitability of private investors. With the need to use the optimal number of people to execute the required tasks came the change of the organisation structure five times within six years. There is therefore a need to develop an optimal organisational structure that efficiently serves to benefit the organisation, which is the research problem of this work.

1.2 Aim and Objective of the Study

1.2.1 Aim

This study aims to design an optimal organisation structure for Steam Power Plant X. using an operation research paradigm.

1.2.2 The objectives of the study

The objectives of this study are:

1. Examine the existing organisational structure of Steam Power Plant X.
2. Apply the personnel utilisation model to redesign the organisation structure of Steam Power Plant X.
3. Compare the redesigned and existing structure of Steam Power Plant X

1.3 Scope of the Study

This research was carried out to design an optimal organisational structure of a privately-owned steam power plant with a focus on the operations and maintenance departments.

2.0 Literature Review

The push for efficiency during the industrial revolution led to a more strategic approach to organisation design. Since then, a lot of scholarly research have been presented but Mcmillan (2002) opined that the principles surrounding organisation design are still not well understood.

2.1 Organisation Design Theory and Principles

Organisational structures are designed based on some design theories and principles. For organisations with an already existing structure, these theories and principles are applied to redesign the structure for optimal performance Hax and Majluf, (1981, as cited by Charles-Owaba, 2002). The principles for the design of any organisation structure must be well understood and in tune with the main goal of the organisation which is for it to yield productive results (Taylor, 1911; Mcmillan 2002; Fauzi *et* al 2021).

Hax and Majluf (1981) identified four organisation design theories: the classical theory, the human relation theory, the contingency theory and the decision-making theory. While the other three theories are qualitative, the classical theory is more quantitative than the others. Lægaard and Bindslev (2014) further reviewed four classical theoretical schools that give insight into organisations that focus on task performance and structure. They are;

1. F.W. Taylor – Scientific management
2. Henri Fayol – Administrative theory
3. Weber – Bureaucracy and Organisation Structure
4. Simon – Administrative Behaviour

Businessmanagementideas.com (2021) submitted that these classical schools of thought rest on four key pillars; Division of labour, Scalar and Functional Processes, Structure and Span of Control.

While it has been established that the type of organisation a company chooses has a long-term impact on the performance of the firm (Sinqobile and Alan 2019), Stewart (1999) and Akindele (2019) agreed that a scientific and quantitative method is required to get optimally performing organisation structures, these methods are few when compared to the years of scholarly work done in the field so far Charles-Owaba (2002).

Alberts (2012) supporting the notion above, stipulated that to design organisational structures that suit the ever-increasing complex organisations, there is a need for designers to:

1. Increase their views of today's complex organisations
2. Ensure design options include what can work for today's complex organisation
3. Ensure design criteria are measurable and adaptable.

Charles-Owaba (2002) in his ground-breaking research proved that a mathematical model can be used to develop a quantitative structure for today's complex organisations. He used the operation research paradigms of theory, alternatives, criticism, evaluation and choice. He developed two models: a Personnel Utilisation Model for maximising the personnel in an establishment; and a Manpower Waste Model for minimising manpower loss in an establishment Akindele (2019). Taha (2007) also developed a quantitative model that combines the parameters and variables of an organisation using queuing theory. Ismaila. et al. (2009) also used the queuing theory to assess the need for manpower in a manufacturing firm. To guarantee optimal organisational structure with maximum personnel utilisation, Ofiabulu and Charles-Owaba (2013) reformulated the organisation's personnel utilisation model as a dynamic programming model. Using the existing heuristic solution method and dynamic programming algorithm, the model was used to determine the variables of a manufacturing firm's management structure. Akanbi et al. (2015), applied the personnel utilisation model to redesign the structure of a publicly owned production organisation; using the model to optimise labour requirement for the company saving a yearly cost of N8,018,544 if adopted. This work now also attempts to apply the model developed by Charles-Owaba (2002) to redesign and optimise the organisational structure of a privately owned steam power plant. The human utilisation of the optimised structure can then be measured using the expression below:

Human utilisation (H_{ij}) is defined as the proportion of man-hours spent on useful work to the total establishment man-hours provided for work.

Mathematically human utilisation is defined as:

$$H_{ij} = \frac{Man - hoursactuallyspentforusefulwork}{Totalestablishment'sman - hoursprovidedforwork}$$

Man-hours spent on useful work is given by:

$L_q + L_w + L_b$

Total establishment's manhours provided for work is given asL_z. Hence,

$$H_{ij} = \frac{L_g + L_w + L_b}{L_z} \quad 1$$

but$L_g = L_{ij}(A_{ij} - W_{ij})$ 2

$$L_w = (K_{ij} - L_{ij})A_{ij} \quad 3$$

$$L_b = (1 - P_{ij})A_{ij} \quad 4$$

$$L_z = A_z K_{ij} + A_{ij} = A_{ij}(K_{ij} + 1) \quad 5$$

Combining expressions 2, 3, 4 and 5 into 1

$$H_{ij} = \frac{L_{ij}(A_{ij} - W_{ij}) + (K_{ij} - L_{ij})A_{ij} + (1 - P_{ij})A_{ij}}{A_{ij}(K_{ij} + 1)} \quad 6$$

By mathematical manipulation, expression 6 becomes:

$$H_{ij} = 1 - \frac{L_{ij} W_{ij}}{A_{ij}(K_{ij} + 1)} - \frac{P_{ij}}{K_{ij+1}} \quad 7$$

By Kendall's notation with one channel queuing model (Taha 1976); m/m/1:(FCFS/K_{ij}/K_{ij})

$$L_{ij} = \bar{L}_{ij} + 1 - P_{ij} \quad 8$$

$$W_{ij} = \frac{\bar{L}_{ij} + 1 - P}{(1 - P_{ij})\mu_{ij}} \quad 9$$

$$P_{ij} = \left(1 + \sum_{n=1}^{kij} C_n^{kij} n!\, e_{ij}^n\right)^{-1} \quad 10$$

$$\bar{L}_{ij} = \frac{\sum_{n=2}^{Kij} (n-1) C_n^{kij} n! e_{ij}^n}{1 + \sum_{n-1}^{kij} C_n^{kij} n! e_{ij}^n} \quad 11$$

Where $e = \frac{\gamma_{ij}}{\mu_{ij}}$ 12

Combing expressions 8, 9, 10, 11 and 12 into 7

$$H_{ij} = 1 - \frac{1}{A_{ij}(K_{ij}+1)} \left[\frac{\frac{\sum_{n=2}^{K_{ij}} (n-1) C_n^{kij} n! e_{ij}^n}{1 + \sum_{n=1}^{Kij} C_n^{kij} n! e_{ij}^n} + 1 - \left(1 + \sum C_n^{Kij} n! e_{ij}^n\right)^{-1}}{\mu_{ij} \left[\left[\sum_{n=1}^{K_{ij}} C_n^{kij} n! e_{ij}^{n-1} \right]^{-1} \right]} \right] - \frac{1 + \sum_{n=1}^{Kij} C_n^{kij} n! e_{ij}^n}{K_{ij} + 1} \quad 13$$

Expressing H_{ij} in terms of decision centre j parameters i and the variables.

$$H_{ij}\left(K_{ij}, A, \mu_{ij}\lambda ij\right) = 1 - \frac{1}{A_{ij}(K_{ij}+1)}\left[\frac{\frac{\sum_{k=2}^{kij}(n-1)C_n^{kij}n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n}{1+\sum_{k=2}^{kij}C_n^{kij}e_{ij}^n}+1-\left[1+\sum_{n=1}^{kij}C_n^{kij}n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n\right]^{-1}}{\mu_{ij}\left[1-\left(\sum_{n=1}^{kij}C_n^{kij}n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n\right)^{-1}\right]}\right] - \frac{1+\sum_{n=1}^{kij}\left(C_n^{kij}n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n\right)^{-1}}{K_{ij}+1}$$

14 (Charles-Owaba 2002)

2.2 Definition of Terms for Personnel Utilisation

L_{ij} Average number of arrivals for supervisor or manager's attention in a day at decision or management level i, decision position j.
W_{ij} Average waiting time of subordinates at decision level i, position j
P_{ij} Probability of having no one attended to by the supervisor at the decision centre $(_{i,j})$.
A: Available working hours per period for each subordinate and superior.
K_{ij}: Number of subordinates reporting to centre j at the *i*th level.
H_{ij}: Human resource utilisation function at decision level i, position j.
L_q: Average daily man-hours spent working by a subordinate who left their workstation to seek information from the superior.
L_w: Daily man-hours spent by a subordinate who had no reason to seek information from the boss'
L_b: Daily man-hours spent working by the head of unit / superior at decision centre (i, i).
L_z: Daily man-hours scheduled for work by both subordinate and superior.
H: Human utilisation for the entire organisation.
N_o: Number of operation positions that performs terminal activities
Note:
i = 1,2…M
j = 1,2…N,
λ_{ij}: Rate at which subordinates at centre j of level i consult the boss at decision centre(i,j).
μ_{ij}: Rate at which superior's spent with subordinates at decision centre $(_{i,j})$.
P_{ij}: Utilisation factor: traffic intensity for the system $\left[\frac{\lambda_{ij}}{\mu_{ij}}\right]$

M: Total number of decision levels (hierarchy)
N_i: Number of decisions, the position at level position
N_1: Number of supervisory positions at level 1
N_2: Number of purely decision or management position at management level 2.
N_m: =1: Chief Executive Position
M, N_i, K_{ij}, N_m: Organisation structure variables
N_o, A, λ_{ij},μ_{ij}: Organisation structure parameters (Charles-Owaba 2002).

3.0 Methodology

3.1 Primary Data Collection

The steam power plant to be optimised was visited and adequate data collection and examination was carried out both for existing organisation structure and independent field observation. The observations were made for work sampling to determine the amount of work in the organisation, and human dynamic interactions between supervisors and subordinates. The resulting organisation structure was then compared with the existing organisation structure.

3.2 Method for Work Sampling and Human Dynamic Interaction.

To complete both the work sampling and human dynamic interaction requirements of the study, the following tasks were carried out:

1. Determination of the amount of annual work available at operation positions in the form of grand total man hours through element estimate method for work measurement.
2. Determination of the number of operation positions $N_{0.}$

Number of Staff (ops position) = (Grand total standard man-hour per annum) / (Available hours x use factor) (3.1) (Owaba 2002).

N.B for the department that works round the clock (Operations Department), the number of staff required were multiplied by four based on the fact that the tasks require 8760 man-hours per year as against the 2190 man-hours year that is in effect in other departments that work for only 42 hours per week.

3. Determination of the parameter set $\theta_2 = (A_1, \lambda_i, \mu i)$ through experimental observations

$$\lambda_{ij} = \frac{Total\ number\ of\ case\ at\ position\ (i,j)}{Total\ time\ (hours)\ for\ study\ at\ the\ position} \quad (3.2)$$

$$\mu_{ij} = \frac{Total\ completed\ cases\ at\ position\ (i,j)}{Time(hours)\ spent\ to\ treat\ all\ completed\ cases} \quad (3.3)$$

4. Determination of the optimal span of control K_{ij} and the optimal personnel utilisation factor were computed from equation 2.14 after inputting all other parameters.
5. Presentation of the size and shape of the organisation structure from the parameters derived.

3.3 Comparative analysis of the optimised organisation structure to the existing one

After the completion of the organisation design for the power plant, the optimised and existing structure were compared based on the value of their personnel utilisation factors and cost savings in wages.

4.0 Data Presentation, Analysis and Discussion of Result

The following were deduced from examining the existing organisation structure:

1. The organisation works through the year running 24hours daily.
2. The personnel work cycle varies by the department with workers in the shift operations department working for 72 hours in a 12-day cycle while workers in maintenance department work for 40 hours per work plus 2 hours of weekend on-call duty responsibility.
3. The 24-hour work cycle in shift operations provides that there are four shifts and four different sets of workers to cover for each shift. The personnel required for the department is multiplied by four.
4. The average percentage allowance per task is 10%.
5. The factory utilisation factor, U_i=0.75= 75%
6. Hence, the available hours per year per worker =$(365/12) * 72$ =2190 Man-hours.
7. The current organisation structure has a total of 258 operation staff, supervisor and managers responsible for 1317 tasks across 4 departments.

4.1 Determination of the number of operation positions N_0.

Table 1 is the summary of the work measurement done to determine the number of operation positions. The number of staff required for the operations department was multiplied by four as earlier indicated.

Table 1. Summary of the work sampling activity for proposed operation positions

Summary				
Total activities measured		1317		
	Grand total man hours	Use factor	Available hours	N_o
Operations*	41180.621	0.75	2190	4 (25.072)
Electrical	19722.207	0.75	2190	12.007
Instrumentation and control	6423.413	0.75	2190	3.911
Mechanical	30958.908	0.75	2190	18.849
Total	98285.149			135.055

4.2 Determination of Human Dynamic Parameters, Personnel Utilisation and shape for the Optimised Structure

With the number of operators at the lowest level determined, the second part of the project involved calculating other parameters of the design function using the human dynamic interaction at every decision level λ (The rate at which the cases were brought to the supervisor) and μ (The rate at which the supervisor attended to the subordinate). Using these values, optimal values for **K_i* and H_i*** for each decision levels (Table 2),

Table 2. Summary of organisation structure parameters by level

i	λ_i	μ_i	K_i*	H_i*	N_i^*
0					135
1	3.041	19.393	10	0.9851	14
2	4	7.042	4	0.964	4
3	2.424	4.717	4	0.953	1

the overall personnel utilisation was then calculated using the expression below.

$$H^*\left(K_{ij}, N_{ij}, M, \theta_n\right) = \frac{\sum_{i=1}^{M}\sum_{i=1}^{N_i}(H_{ij})}{\sum_{i=1}^{M}(N_i)} \qquad 15$$

Where $\theta_n = (A_{ij,ij}, \mu_{ij}\ N_0)$.

Thus, form expression 16

$$H^* = \frac{(N_1^*\ x\ \ H_1^*(K_1^*, A, \lambda i, \mu_i) + (N_2^*\ x\ \ H_2^*(K_2^*, A, \lambda_2, \mu_2) + (N_3^*\ x\ \ H_3^*(K_3^*, A, \lambda_3, \mu_3) + (N_4^*\ x\ \ H_4^*(K_4^*, A, \lambda_4, \mu_4)}{N_1 +\ N_2 + N_3 + N_4}$$

$$H^* = \frac{14(0.9851) + 4(0.9644) + 1(0.9531)}{13 + 3 + 1} = \frac{18.6021}{19}$$

$$H^* = 0.9791$$

$$= 97.91\%$$

Hence, the overall personnel utilisation is thus at 97.91%.
The size and shape of the organisation are computed as follows:
$S^*(size) = N_0 + N_1 + N_2 + N_3 + N_4$
$S^*(size) = 135 + 14 + 4 + 1$
The height of the organisation M* = 3

The width of the organisation, Z = $(N_1 + N_2 + N_3)/M^* = \frac{14+4+1}{3}$

$$= 6\ \ (to\ the\ nearest\ whole\ number)$$

The organisation structure is thus given as:

$$\in = (S\ M^*Z) = (154, 3, 6)$$

This is presented in the matrix below;

$$\in = \begin{bmatrix} 3 & 1 \\ 2 & 4 \\ 1 & 14 \\ 0 & 135 \end{bmatrix}$$

This is the proposed organisational structure for the Steam Power Plant.

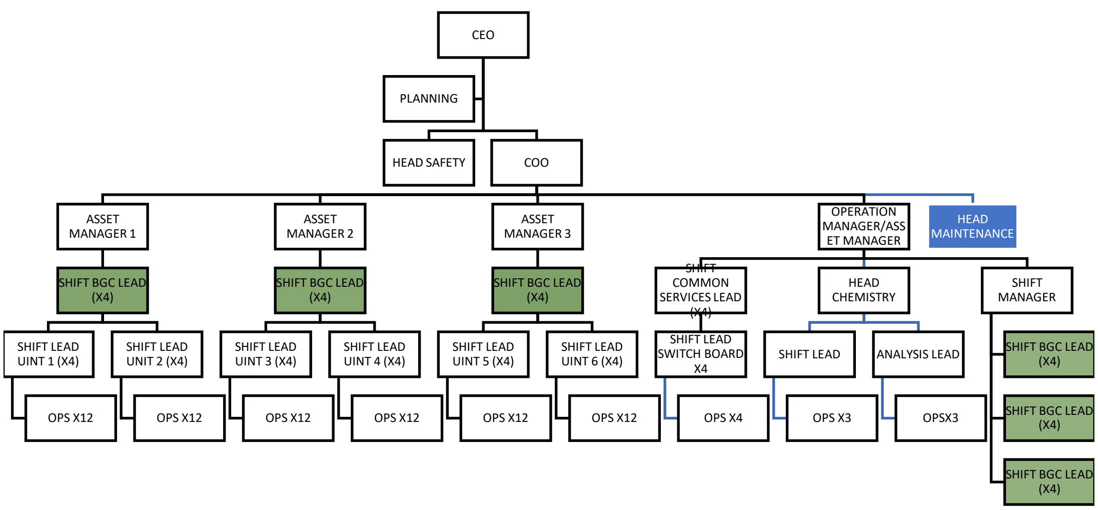
4.3 Comparison of Existing and Proposed Structure

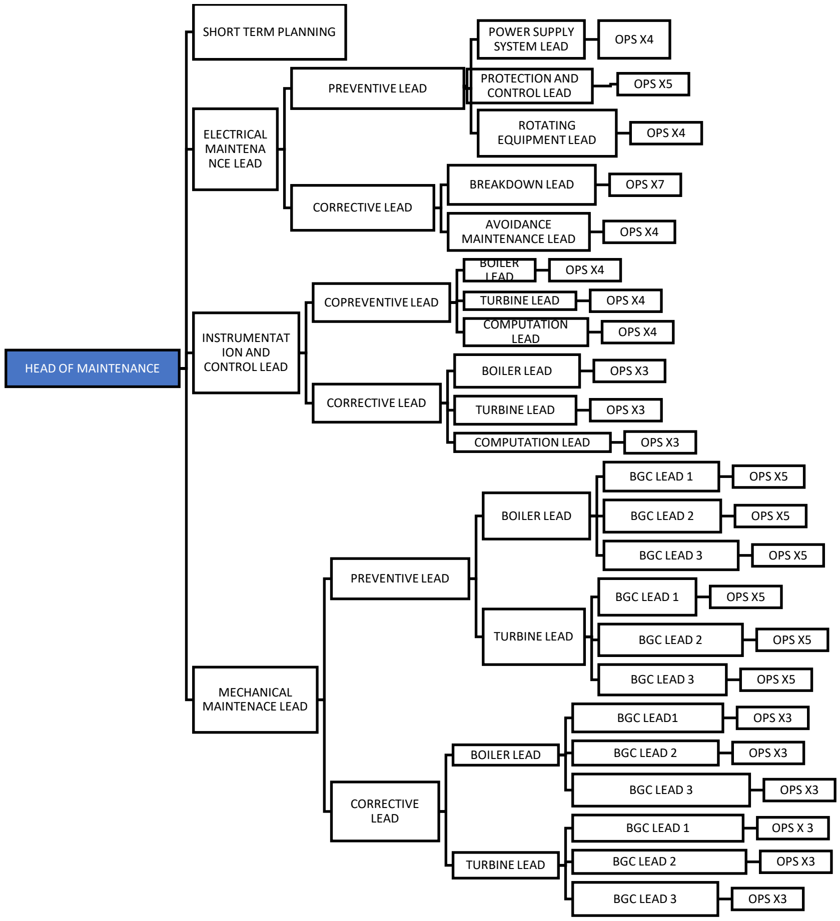
The existing and proposed structure comparison information is highlighted in table 3. The required changes in personnel population are highlighted in the 5th column. A negative prefix before the numbers means that there is a need for additional staff, while the positive prefix means a reduction of the staffers. The table revealed that the original structure was not staff deficient but excessive in many areas.

Table 3. Comparison table of the existing and proposed structure

S/N	Positions	Existing	Proposed	Difference (Desired Reduction)
1	Third level Manager	1	0	0
2	Second level Manager	5	1	4
3	First level manager position	24	4	20
4	Supervisory positions	53	14	29
5	Operation position	175	135	40
	Personnel utilisation	85.53%	97.91%	-12.38%
	Cost	N32,940,000	N16,590, 000	N 16, 350, 000

The existing and redesigned organisation structures are presented below in figures 1(a), 1(b) and 2. The optimized organisation structure in addition to its potential cost benefit, presents a simplified reporting line which potentially can help improve quality of work as a result of its more evenly distributed communication channel.





Figures 1(a) &(b). Existing Organisation structure within the power plant

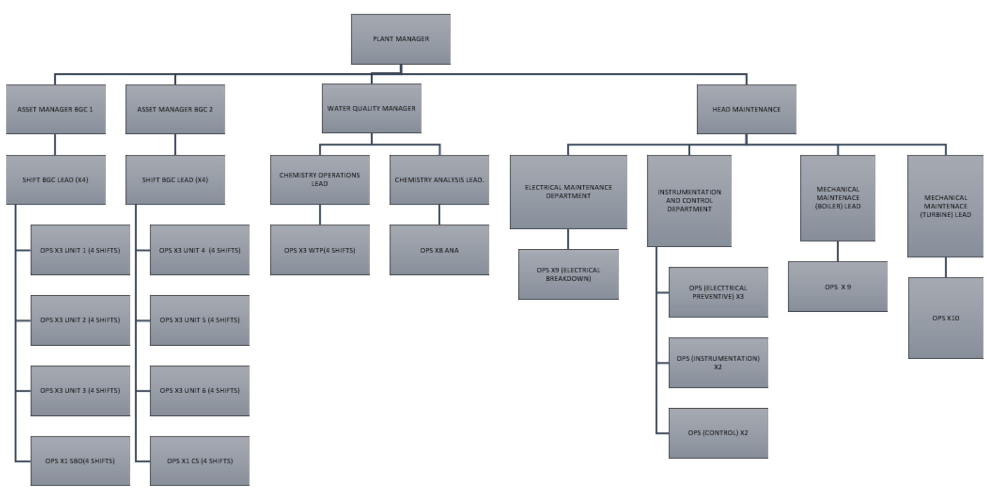


Figure 2. Redesigned organisation structure of the Steam Power Plant showing a more simplified reporting line

5. Discussion of Results

The data gathered from the work analysis exercise revealed that certain activities have far more redundancies factored into them than is expected for personnel whose performance rating is 100% or more. While some job roles remained, there was a need to reorganise in order to have an efficient system.
The span of control at the second and third levels of the existing organisation structure compares more favourably with the optimised organisation structure, but the optimised structure rendered the third decision level unnecessary.
The proposed organisation structure when compared with the existing structure makes performance measurement and human dynamic interaction easier as it eliminates the one subordinate to two bosses reporting lines that were found in the existing organisation structure. Financially, the optimised organisation structure proved to be very cost-effective as the funds required to pay the wages of personnel for a month in the existing structure will now pay for almost two months after trimming down to the optimal structure.

5. Conclusion

Personnel utilisation mathematical expression was formulated in terms of organisation design variables and parameters and applied as a design objective function. This confirmed the practicality of applying the quantitative approach to solving the organisation design problem.

The redesigned organisation structure was compared to the organisation's existing structure and it performed better than the existing structure. This gives credence to the viability of the quantitative approach as a tool for organisation's design optimisation.

References

Akanbi, O. G., Ismaila, S. O. and Awodola, J. G. 2015. Quantitative methods in the designs of organizations: a model and a real-world application. *Technical Journal*. Vol. 9 no. 2, pp: 121-127, 2015.

Akindele, J.O., Redesigning of the organisation structure of a manufacturing firm (a case study of British American Tobacco, Ibadan). M Sc Project Thesis Dept. of Industrial and Production Engineering. University of Ibadan , 2019.

Alberts, D.S. 2012. Rethinking organizational design for complex endeavours. *Journal of Organization Design. 1. 14-17*

Charles-Owaba, O. E.. Organizational design: a quantitative approach. Ibadan. Oputoru books. ISBN: 978-8014-47-X, 2002

Fauzi, T., Santosa, P., Purwanti, Y & Nurhayati, N). The effect of internal elements of strategic management of organizational structure, management role and employee behavior on corporate mission.*Management Science Letters* , vol. 11, no. 4, pp. 1189-1196, 2021.

Hax, C. and Majiluf, N.S. 1981. Organizational design: A survey and an approach, Operations Research. Vol. 29, No. 3. Pp: 417-447

Ini, N.U.. Determination of an optimal number of nurses required in a university teaching hospital. M Sc Project thesis Dept. of Industrial and Production Engineering. University of Ibadan, 2019.

Lægaard, J. and Bindslev, M.. Organisational theory. Ventus Publishing AsP. 112pp, ISBN 87-7681-169-7, 2014.

McMillan, E..*Using Self Organising Principles to create effective project teams as part of an organizational change intervention*. A case study of Open University, in complexity and complex system in Industry, McCarthy, I. and Rakotobe-Joel, T.eds. University of Warwick, UK., 2002.

Ofiabulu, C. E and Charles-Owaba, O.E A personnel cost model for organizational structure design. *Journal of the Nigerian Institute of Industrial Engineers*. Vol. 3 no. 6, 2013.

Őnday, Ő.. Classical Organization Theory: From Generic Management of Socrates to the bureaucracy of Weber. *International Journal of Business and Management Review* Vol.4, No.1, pp.87-105, 2016

Sinqobile, W.N and Alan, S.P., An investigation of the impact of organisational structure on organisational performance. *Financial Risk and Management Reviews vol.* 5. pp. 10-24, 2019.

Stewart, R. The Reality of Management, third edition, Butterworth-Heinemann, 1999.

Taha, H.A.. *Operations Research*: An Introduction. Mcmillan New York, 2007.

Taylor, F.W., The principles of scientific management. New York: *Harper & Brothers*, 1991.

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