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Mathematical Tools Analysis for Effective Engineering and Technology Management Decisions

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Abstract - **Mathematical tools play a vital role in any organization which makes the value of information depends on its application and use. Decision making is one of the most important functions performed by engineers in their domain. The future profitability and viability of engineering and technology management domain depend on effective decision making. The success of any mathematical tools in an organization largely depends on the quality of information that it generates that makes the process very effective and efficient when the large amounts of data is involved. This paper makes attempt to highlight the mathematical tools for making the better decisions in engineering and technology management domain. The theorems provided enable the critical features of the decisions in the field to be ascertained and techniques discussed for obtaining the underlying mathematical functions. However, the last decade's changes in engineering and technology management spending and the global economy make the quality and timeliness of decisions more critical to success than ever before.**

Keyword*: *Decision, Engineering, Information, Management, Mathematical Tools, Organization, Technology

I. INTRODUCTION

A mathematical tool is the preferred means for learning about the critical features of the effective engineering and technology management decisions and functions. In today's competitive and global economy, an effective management of engineering and technology is very important for the survival of a business functions. Engineering and technology management is basically concerned with managing engineering and technologies to achieve business objectives or goals. It requires skills in understanding technology and engineering in addition to managing business activities of organizations. Research into the use of mathematical tools in engineering and technology management domain is extremely diverse which tends to encompasses the many different characteristics of business, including size, culture, business strategy, attitudes to IT, industry and location, to name a few. An engineer's mind is generally very heavily enriched in the fields of sciences and mathematics, with the absolute minimum emphasis placed on the so-called humanities and other social sciences. The stress placed on scientific knowledge is done with good reasons, since an engineer's function when he reaches field of domain is to translate for the optimum use of mankind the physical laws of the universe and the natural materials available. In order to accomplish this, an engineer seeks to question situations, phrase problems, gather evidence, weigh values and options, strike balances, make judgments, and direct conduct. Most of this activity is on inanimate objects, with normally predictable results. That is where mathematical tools come to play in some vital decisions. Therefore, Decisions drive organizations. From the top management to the lowest, every minute of the day someone is making a decision that has an impact on the organization's performance [1].

II. LITERATURE REVIEW

In olden days, 1325 AD to be more precise, an engineer was defined as "a constructor of military engines". Back then engineering was divided into two categories: Military Engineering and Civil Engineering. The exact origin of the word 'engineering' comes from the era when humans applied themselves to skilful inventions. Man evolving further in the world invented devices such as the pulley, the wheel and levers. The word 'engineer' has its root in the word engine, which comes from the Latin word *ingenium*, which literally means natural talent or capacity as well as "a clever invention"[2] and thus the word engineer emerged as a person who creates nifty and practical inventions. The master works of ancient Persian, Greco, Roman, Chinese, and Scythian civilizations all involved engineering to various degrees, and the individuals responsible for those discoveries and enterprises were in the every respect engineers [3].

Although, the history of modern management begins with the Industrial Revolution which was as the result of the development of the steam engine by James Watt in the eighteenth century. Two engineers who may be called the fathers of modern management were Frederick W. Taylor (1856–1915) and Henri Fayol (1841–1925). In Frederick W. Taylor's views concerning management were finding the most appropriate method for performing a job and assigning the right person for each job. Henri Fayol outlined 14 principles of management, including division of work, discipline, line of authority, initiative, order, and centralization in a book published in 1916, titled

Administration Industrielle et Generale covering most of his thoughts on management [4, 5]. F. B. Morse was another factor that played an instrumental role during this period by developing the telegraph which was first experimental telegraph line in 1844, and by 1860 there was a total of 50,000 miles of telegraph line in the United States [3].

Before 1835, there were only 36 firms in the United States that employed more than 250 workers [4]. During the last decade of the nineteenth century, persons such as Mike Adenuga, Jimoh Ibrahim, Aliko Dangote and the likes of John D. Rockefeller, Andrew Carnegie, and Cornelius Vanderbilt took advantage of telecommunications, oil and gas, railroads and other conglomerates to build big corporations employing thousands of people. In turn, this led to the need of a systematic approach to managements [3, 5]

III. ENGINEERING, TECHNOLOGY AND MANAGEMENT

Both modern engineering and technology interface with mathematics, physical sciences, social sciences, and humanities. An effective understanding of the former is absolutely necessary to translate innovative ideas into reality while due regard for the latter is critical for business success [6, 7]. Before venturing far, we should assure a common understanding of the phenomena of engineering, technology and management.

- Engineering: This is the application of scientific, economic, social, and practical knowledge in order to invent, design, build, maintain, and improve structures, machines, devices, systems, materials and processes [20].
- Technology: This is an advanced scientific knowledge used for practical purposes especially in industry
- Management: The manipulation of the resources of an organization such as men, money, and materials toward the end of achieving the objectives of the organization.

Nonetheless, in the modern terms the words “technology” and “engineering” may simply be described as the knowledge to manipulate nature to produce products (consumer, industrial, and commercial), energy, and services; and the understanding of the manipulation process that seeks to satisfy human social and economic needs and aspirations, respectively. The factors in management to manipulate may be described and classified into principles, methods, techniques, mechanisms, selection and coordination [8].

i. Principles: Principles of management have been developed through the years through experience, experiment, description, classification, and analysis.
ii. Methods: Methods are systematic ways of carrying out management functions.
iii. Techniques: Techniques are devices for carrying out methods in accordance with principles.
iv. Mechanisms: Mechanisms for management include devices such as office machines and communications equipment.
v. Selection: Selection is the factor which describes decision-making in management, in the manipulation of resources -- men, money, and materials.
vi. Coordination: Coordination is the placing of other factors of management and the resources of management into the most effective relationships for realizing the objectives of the organization.

IV. MATHEMATICAL TOOLS METHODOLOGY

In today’s fiercely competitive global economy, an effective management of engineering and technology is crucial for the survival of business and the maintenance of national prosperity. The motivation in this domain is the engineers. It is through engineers that principles are carried out, methods are put into operation, techniques are applied, and mechanisms are utilized. It is the same engineers who carry out the process of selection which accompanies all management action. Engineers must be motivated to act in the ultimate interest of the organization. Motivation is the most subtle, the most elusive, the most fragile, and the most important of all engineering and technology management factors. Some examples of these methods are linear and nonlinear programming techniques. Today’s engineering and technology managers make use of various types of methods and approaches include discounted cash flow analysis, depreciation analysis, decision trees, optimization techniques, learning curve analysis, fault tree analysis, forecasting and intelligence techniques.

a. Discounted Cash Flow Analysis

These play vital roles in the time value of money as “Compound Interest and Present Value”, and “Uniform Periodic Payment Amount and Present Value”. Mathematically, Compound Interest and Present Value, at the end of the first period the amount is expressed by

$$A_1 = A + A_i = A(1 + i) \quad (1)$$

where

i is the interest rate per period (usually, it is a year).

A is the original amount or principal.

A_1 is the compound amount at the end of the first period or year.

At the end of nth period (or year), the amount is generalized to the following form:

$$A_n = A_{n-1}(1+ i) \quad (2)$$
$$= A\,(1+ i)^n \quad (3)$$

where

A_n is the compound amount at the end of the nth period or year.

A_{n-1} is the principal amount for the nth period or year.

The total compound interest, I, earned after the nth period or year is expressed by

$$I = A_n - A \quad (4)$$

The value of a single payment is expressed by

$$A = A_n\,(I + i)^{-n} \quad (5)$$

The Uniform Periodic Payment Amount and Present Value assumed that at the end of each of the n equal periods or years, the depositor adds X amount of money and the total amount is expressed [9, 10]

$$TA = X(1 + i)^{n-1} + X(1 + i)^{n-2} + X(1 + i) + X \quad (6)$$

$$PV_s = \frac{X[1-(1+i)^{-n}]}{i} \quad (7)$$

where

TA is the total amount of money

$X(1 + i)^{n-1}$ is the value of X after (n-1)periods or years

$X(1 + i)^{n-2}$ is the value of X after (n-2) periods or years

$X(1 + i)$ is the value of X after one period or year

PV_s is the present value of uniform periodic payments.

b. *Depreciation Analysis*

The word *depreciation* simply means decline in value. As engineering systems become older, they decline in value. Thus, depreciation analysis is basically concerned with considering the change in the value of items with various methods of realizations such as *sum-of-the-years-digits* (SYD), declining-balance depreciation and straight-line depreciation method [11]. In terms of the *sum-of-the-years-digits* (SYD) method, the approach provides a larger depreciation charge in the early years of the item's useful life than in the later years. The annual depreciation charge is expressed by

$$ADC = \frac{2(L-BY+1)(PC-SV)}{L(L+1)} \quad (8)$$

Therefore, the item book value at the end of year BY is given by

$$BV_{BY} = \frac{2(PC-SV)[1+2+---+(L-BY)]}{L(L+1)} + SV \quad (9)$$

The declining-balance depreciation method accelerates write-off item cost in early productive years and the years less close to the final life. The *depreciation rate* (DR) is expressed by

$$DR = 1 - \left(\frac{SV}{PC}\right)^{\frac{1}{L}} \quad (10)$$

Therefore, the annual depreciation charges, ADC_{BY} at the end of BY is given by

$$ADC_{BY} = BV_{BY}(BY-1)\left[1-\left(\frac{SV}{PC}\right)^{\frac{1}{L}}\right] \quad (11)$$

In the studies of depreciation, straight-line depreciation method and is probably the most widely used in which approach assumes constant annual depreciation during the item's useful life. Thus, the annual depreciation charge and the item book value at the end of BY are given by

$$ADC = \frac{PC-SV}{L} \quad (12)$$

$$BV_{BY}(BY) = PC - \left[\frac{(PC-SV)BY}{L}\right] \quad (13)$$

where

ADC is the annual depreciation charge.

PC is the procurement cost of item.

L is the item's useful life.

BY is the year of item book value.

SV is the salvage value.

c. *Optimization Techniques*

The two best known optimization techniques are Lagrangian multiplier and Linear programming which are useful to engineering management professionals [12, 13] but others such as Mixed-Integer Programming (MIP) and Network flow Programming (NFP) are good not all that popular compared to the two mentioned above. In a technique with two-variable function that can be extended to m variables, the Lagrangian multiplier approach allows the optimization of functions subject to constraints without the elimination of any variables. Thus, we define function $f(x_1, x_2)$ subject to the constraint function $g(x_1, x_2) = 0$. In this case, we write the Lagrange function as follows [14, 15]:

$$\frac{\delta L(x_1,x_2,\lambda)}{\delta x_1} \quad (14)$$

$$\frac{\delta L(x_1,x_2,\lambda)}{\delta x_2} \quad (15)$$

$$\frac{\delta L(x_1,x_2,\lambda)}{\delta \lambda} \quad (16)$$

where

λ is the Lagrange multiplier.

$L(x_1, x_2, \lambda)$ is the Lagrange function.

Linear programming method is probably the simplest and the most widely used method of optimization subject to constraints is, Past experience indicates that the application of the linear programming method has helped production and operations engineers plan and make effective decisions to allocate available resources [16, 17]. The objective function: Maximum (or minimize) is expressed by

$$P = c_1y_1 + c_2y_2 + \text{------} + c_ny_n \quad (17)$$

which is subject to following constraints of equation equation (18) to equation (23)

$$a_{11}y_1 + a_{12}y_2 + \text{---} \; a_{1n}y_n \; (\leq, =, \geq) \; R_1 \quad (18)$$

$$a_{21}y_1 + a_{22}y_2 + \text{---} a_{2n}y_n \; (\leq, =, \geq) \; R_2 \quad (19)$$

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| | | | | |

$$a_{m1}y_1 + a_{m2}y_2 + \text{---} \; a_{mn}y_n \; (\leq, =, \geq) \; R_2 \quad (20)$$

$$y_1 \geq 0 \quad (21)$$

$$y_2 \geq 0 \quad (22)$$

|

|

$$y_m \geq 0 \quad (23)$$

where

m is the number of constraints.

n is the number of variables.

P is the profit (or cost).

yi is the ith variable; for i = 1, 2, -, n.

Rj is the jth resource; for j = 1, 2, -, m.

ci is the ith constant; for i = 1, 2, -, n.

aji is the (j, i) constant; for j = 1, 2, -, i

i = 1,2,-, n.

Mixed Integer Programming (MIP) problems involve the Optimization of a linear objective function, subject to linear equality and inequality constraints. MIP is extremely demanding of computer resources, and the number of discrete variables is an important indicator of how difficult an MIP will be to solve.

$$\min_{x,z} \quad f_1^T x + f_2^T z \qquad (24)$$

$$\text{subject to } A_1 x + A_2 z \leq b \qquad (25)$$

where z is the integer

Network Flow Programming (NFP) is a specialized linear programming which is characterized by simple manipulation and rapid convergence. This section presented the network flow model using the out - of – kilter algorithm (OKA) conditions for solving engineering problems

$$\text{minC} = \sum_{ij} C_{ij} f_{ij} \quad ij \in m \qquad (26)$$

such that

$$\sum_{j \in n} \left(f_{ij} - f_{ji}\right) = r_i \quad i \in n \qquad (27)$$

$$L_{ij} \leq f_{ij} \leq U_{ij} \quad ij \in m$$

where

C_{ij} is the arc cost per unit flow

f_{ij} is the flow on arc *ij* in the network

L_{ij} is the lower bound of the flow on arc *ij* in the network

U_{ij} is the upper bound of flow on arc *ij* in the network

n is the total number of the nodes in the network

m is the total number of the arcs in the network

d. *Learning Curve Analysis*

This is found to be quite useful in a variety of applications such as internal labour forecasting, production planning, external purchasing strategic evaluation of company and industry performance. The theory is based on assumptions such as that, the time required to complete a specified task or unit of a product or item will be less each time the task is performed; the unit time will reduce at a decreasing rate and the decrease in time will follow a certain pattern, such as negative exponential distribution shape.

$$LH_m = LH_1 m^c \qquad (28)$$

$$c = \frac{\log \text{ of the learning rate}}{\log 2} \qquad (29)$$

where

LH_m is the labor hours required to produce unit *m*.

LH_1 is the labor hours to produce unit one or the first unit.

c is the learning curve slope

e. *Fault Tree Analysis*

This is a widely used method in industry to perform reliability analyses of engineering systems. The events that could cause the occurrence of this top event are generated and connected by logic gates called OR, AND, and so on. The technique is called fault tree analysis because it only considers failure or negative events, and a fault tree may simply be described as the logic structure relating the top event to the basic fault events. The probability of occurrence of the OR and AND gate output fault event are expressed below

$$P_{OR} = 1 - \prod_{i=1}^{n} (1 - P_i) \qquad (30)$$

$$P_{AND} = \prod_{i=1}^{n} (1 - P_i) \qquad (31)$$

where

P_{OR} is the occurrence probability of the OR gate output fault event.

P_{AND} is the occurrence probability of the AND gate output fault event.

n is the number of gate input fault events.

Pi is the occurrence probability of the input fault event *i*, for

i = 1, 2, -, *n*.

The fault tree analysis concept can also be applied in making various types of engineering and technology management-related decisions.

f. *Forecasting*

Each day engineering managers make various decisions that are concerned with some point in the future which predicting the rates of technological progress that may lead to the development of new products requiring new plants and equipment [1]. The success of any forecast depends on the effectiveness of the approach followed in forecasting. A useful forecasting approach is composed of the following eight steps [13]:

i. Determine the forecast application and objective.
ii. Choose with care the items to be forecasted.
iii. Determine forecast time horizon (i.e., long, short, or medium).
iv. Choose appropriate forecasting model(s).
v. Collect the appropriate data required to make the forecast under consideration.
vi. Validate the forecasting model with care.
vii. Make all relevant forecasts.
viii. Implement the appropriate results.

The demand forecasts are concerned with projecting demand for an organization's products or services that in turn drive company's production, capacity, and scheduling systems, and serve as inputs to areas such as marketing, finance, and personnel planning. Economic forecasts are concerned with predicting factors such as inflation rates, money supplies, housing starts, and other planning indicators. The forecasting methods may be divided into two broad categories: qualitative and quantitative. The qualitative methods provide forecasts that incorporate factors such as the decision maker's emotions, personal experiences, and intuition. The quantitative methods provide forecasts that can be obtained by employing various mathematical models that use past data or causal variables to forecast demand such as exponential smoothing, moving averages, linear-regression causal model, and trend projection.

The forecasting technique selection could be subject to one or more factors, such as the forecast development cost, the availability of historical data, the length of prediction interval, data accuracy, the time for analysis, the expected accuracy from the forecasted result, and the complexity of factors affecting operations in time to come [18, 19]. Two widely used quantitative methods simple average and exponential smoothing method.

In Simple Average, the technique is simple and straightforward which demands of all previous periods are given equal weight. Thus, the simple average of the past is expressed by

$$SA = \sum_{i=1}^{m} D_i / m \quad (32)$$

where

SA is the simple average.
m is the number of all the past demand periods.
Di is the demand for the *i*th previous past period.

whereas the Exponential Smoothing is frequently used and sophisticated weighted moving-average forecasting method and forecasts for one period ahead by weighing the most recent past period data or demand most heavily. The basic exponential smoothing formula is as follows:

$$F_a = \alpha D_{a-1} + (1-\alpha)F_{a-1}, \text{ for } 0 \leq \alpha \leq 1 \quad (33)$$

The generalize version of the above equation as follows:

$$F_a = \alpha D_{a-1} + \alpha(1 - \alpha)D_{a-2} + \alpha(1 - \alpha)^2 D_{a-3} + \text{------} + \alpha(1 - \alpha)^{n-1} F_{a-n} + (1 - x)^n F_{a-n} \quad (34)$$

where

a is the time period.
F_a is the forecast for demand one period ahead.
α is the smoothing constant or the weighting factor.
F_{a-1} is the demand forecast for the most recent past period.
D_{a-1} is the actual demand for the most recent past period.
n is the total number of past periods.

g. Intelligence Methods

The academic research area for developing models, methods, and basic technologies for representing and processing knowledge and for building intelligent knowledge-based systems, is called knowledge engineering. This is a part of the AI area, directed more toward Neural Networks, Fuzzy Logic and Analytical Hierarchical Process [21, 22]

V. CONCLUSION

Over the years professionals working in the engineering and technology management field have been trying to develop various tools for use in business activities and functions. Considerably, there has been a considerable growth in the development of quantitative management techniques and methods. The new developments in computer technology and the complexities of modern management decision making problems have enhanced the importance of many of these quantitative approaches. The uses of the mathematical tools were discussed extensively and formulas presented for various tools for effective engineering and technology management decisions.

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