THE MEN AND MACHINES THAT CHANGE THE WORLD

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UNIVERSITY OF IBADAN

THE MEN AND MACHINES THAT CHANGE THE WORLD

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The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Registrar, Librarian, Provost of the College of Medicine, Dean of Faculty of Technology, Dean of the Postgraduate School, Deans of other Faculties and of students, Directors of Institutes, Distinguished ladies and Gentlemen.

The Importance of Work

Work, a very vital human-based process, is the only known bridge between human desire and its fulfillment; otherwise, desire remains a dream. Webster's New Collegiate dictionary defines work as the "mental and physical effort to overcome obstacles and achieve objectives". The phrase "mental and physical effort", suggests that, except when sleeping, humans are always working. This seems to agree with Groover's (2007) observation that "all have to work during our lives." From Newtonian Physics, we gather that **Work** is the mother of physical **Change** (Halliday et al. 1970).

On the issue of change, a genuine achiever will appreciate the importance of diligent and intelligent work as we are privileged to witness how selfless work is turning a dilapidated university campus into a paradise. Work builds and sustains the greatness of an individual, town, state or nation when carried out scientifically. Unfortunately, it may also destroy when poorly organized and done in a self-centred manner. The power of work is highly desirable as it is capable of turning deserts into farmlands; jungles into cities and natural forces into affordable utilities. Selfless work can transform an annual budget or development plan into attractive national infrastructure with a steady flow of electricity and regular water supply. Galant work can turn a mace breaking legislature into a manna providing one. A good mix of brain and muscle work, propelled by collective willpower, is the secret of all great civilizations (Charles-Owaba 2001e).

Despite its importance, work appears to have escaped the serious attention of ancient philosophers and scientists.

Worldwide, the literature is sparse on comprehensive information to guide humans on what seems to matter most to livelihood (Groover 2007). This lecture is an attempt to aggregate some valuable information on the concept of human work. In particular, the premise that human work is the only known instrument that can bring about monumental change or national development is pursued. It is shown that human work has two components: the pure and applied science. Illustrating purely from a historical perspective, it is argued that work is the instrument used to shrink the world into a global village.

Accordingly, the lecture is in five parts; namely, Human Work Models; The Pure Science of Work; The Applied Science of Work; Historical Perspective; and My Humble Contributions.

Human Work Models

McCormick (1957) proposed an individual work model whose modified version is presented in figure 1.

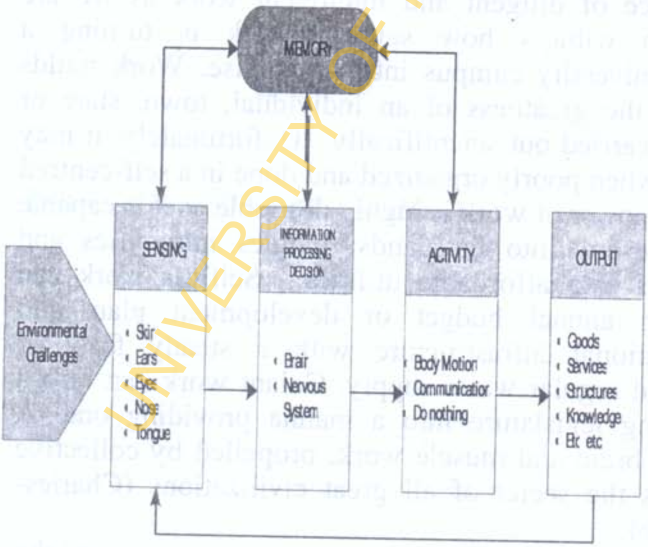

Fig 1: Human Work Model

The model suggests that challenges in form of environmental input data are picked through the human sense organs. These trigger the process of human work. The data are processed by the brain and nervous system. Some additional data may be recalled from memory to give a clearer picture of the challenge. A decision is made on the choice of type and grade of action (activity). The activity is then carried out resulting in some form of output. The information on the quality and quantity of output serves as feedback through the sense organs. Through this mechanism, the same set of activities and output may be repeated severally. Alternatively, another type of environmental challenge may be more appealing at the time. In this case, the worker may respond to a new challenge resulting in a new set of activities and outputs. The memory serves not only as a storeroom for experienced challenges, past decisions and activities but also as the controller of the process.

Considering the individual model, challenges are generated continually by the insatiable nature of human desires. The level of essential needs in the home, one's social status or level of performance at the workplace and the appearance of the immediate environment are a few sources of challenges. It is important to note that the grades and types of challenges as well as the rate of acceptance dictate the types and volumes of activities carried out by an individual. Unfortunately, the choice of challenges and the rate of acceptance vary considerably for individuals, communities and cultures. What one seriously regards as environmental challenge may not appeal to another. Perhaps, this explains why some leaders may occupy a position for years with no unique achievement to show for it. The choice of challenges matters: unique challenges result in unique outputs. He who accepts only the business-as-usual grade of challenges may only get routine results.

As challenges exist in different grades so are activities. There are three major types of human work activities. These are Negative, Neutral, and Positive work activities. Negative activity is physical and mental effort aimed at achieving goals which are inimical to a corporate, community or national interest; neutral is work activity which results in no form of output while positive work is one with a corporate, community or nation's intended output. Embezzlement, bribery, 419 activities, pilfering of corporate resources, willful damage to structures, hoarding of information or resources, and effort to dissuade personnel from work, are typical of negative activities. Absenteeism, loitering during work periods, sheer idleness, gossiping instead of working, doing one's business during working hours, are some examples of neutral activities, while reading one's books by a student, creative thinking by a planner, beautification of the environment by a gardener, are a few cases of positive work activities.

The model shows that outputs are the outcomes of activities. There are also various categories of outputs. It is important to note that **nothing** is one form of output. Others include knowledge, ideas, inventions/discoveries, certificates, policies, finished and in-process goods; services, structures, entertainment, raw and cooked food, to mention just a few. Notice that **work output** is the indicator of desirable **change or development**. Consider, for example, a particular neighborhood in a given period. If new structures like roads, buildings, recreation centers, hospitals and traffic controls are constructed, impartial observers will say, "this neighborhood has changed"; otherwise, "no progress" will be the remark.

The afore-mentioned model explains how an individual works but it is silent on corporate work. Charles-Owaba (2002) suggested a corporate work model as follows:

> A known number of workers report for work daily, each resuming at a fixed period and closing after a fixed interval of work. Within this period, **every individual totally alligns his/her will with a pre-defined collective or corporate will** in return for periodic **reward**. Duty post, immediate boss, reward grade, types of challenges, scope of

activities and output types are pre-specified for each worker. At resumption, each worker reports to his/her duty post to interact with the work environment as per the individual work model and moderated by the corporate will.

(Note that collective will and reward are the most critical components of the corporate work model).

Combining both models, it appears safe to state that

> "organizations or nations which fail to develop a strong collective will and a sound work-based reward system capable of spurring all stake-holders to pursue only positive work are bound to experience retardation or stagnancy".

Perhaps, this explains the reason for the wide developmental gap between the advanced and third world countries. The former tend to exhibit a stronger collective will in the pursuit of positive work.

The Pure Science of Human Work

The human work models explain how and why humans work. They do not account for the factors which influence the human's quality, speed, efficiency, dedication and reliability at work. There are numerous environmental elements which aid or limit human work processes. Murrell (1965) identified three main categories that impact human performance. He calls them "the ambient or general environment, the physical resources or the immediate environment, and the human inherent limiting/aiding factors".

The components in the ambient environment are heat, cold, humidity, wind velocity and pollution. Others include noise, vibration, atmospheric pressure, light/darkness, supporting platform velocity, and acceleration. The components of the immediate environment are tools, machines, other people, materials, space, controls and displays. Others include buildings, layout and location of facilities, furniture, offices, energy sources, information, finance, and clothing. The human inherent elements are anthropometric dimensions such as height, weight, muscle strength, reach and flexibility of joints and the skeletal structure. Others include the sense organs, brain, nervous system, physical work capacity and mental capacity. Still others include sex, age, posture, willpower, incentive and dieting, training, health and rest activities. Murrell's (1965) model of the possible interactions between these three factors and the human work model is presented in figure 2.

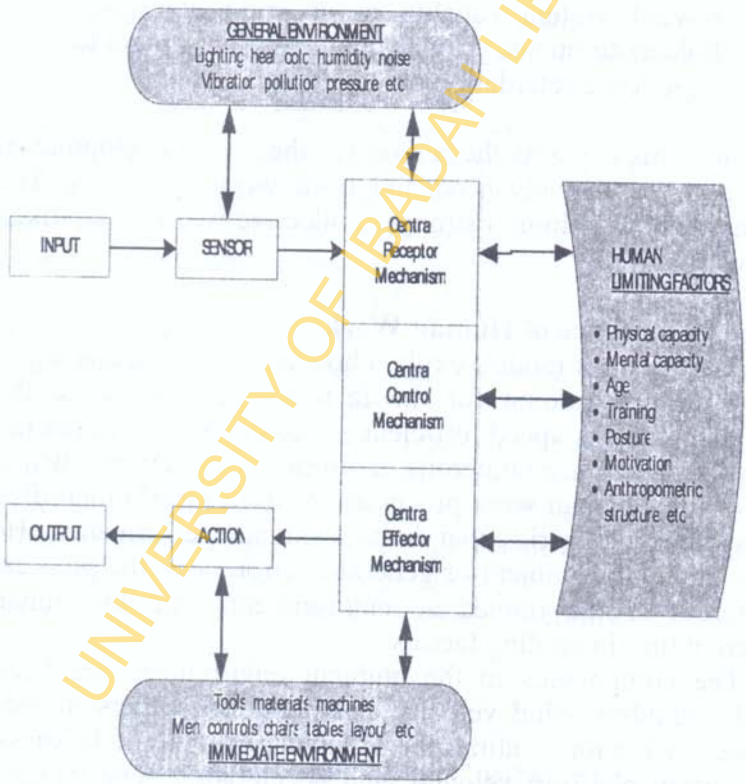

Fig. 2: Human interactions with work environment

On a close examination of the information in figure 2, it is easily demonstrated that the performance of humans at work may be changed by altering the values of one or more elements of the ambient and immediate environments. Consider, for instance, working in a very hot, very cold or heavily polluted environment. Granting that one may even survive, the speed, quality, reliability and dedication of the worker may be significantly different from a normal work situation. It is also well known that some level of prolonged noise will impair the hearing organs while vibration may adversely affect the nervous system (Kroemer et al. 2001). Secondly, the choice of machines, tools, materials, furniture, quality of information, mode of financial supply, and facilities configuration may impact on the grade and speed of human activities. This is also true with differences in human skeletal structure, mental capacity, will-power, aerobic capacity, training, age and sex. Depending on the type of work situation, significant differences have been established between the young and the old, males and females, the trained and untrained, the motivated and unmotivated (Ayoub and Mital 1989).

It may be noted that the elements in the respective environments may also interact either in pairs or multiple combinations to adversely or favourably affect human performance. For instance, the interaction of heat, materials and controls may impact on quality of work (McCormick 1970). Hence, elements in the immediate and ambient environments are variables with infinite ways of combining them to impede or promote human work performance. For instance, hammer, the carpenter's tool can be made of several possible sizes, shapes or weights. Working with too light, too big, too heavy or too awkwardly shaped hammers may result in poor quality, slow pace, or unsafe work. Let us remind ourselves here that the main purpose of work is to attain quality, speed, and varieties of outputs to maximally satisfy human desires. This calls for judicious selection and combination of the values of the work environmental elements, a task which will be unfeasible unless the nature of all the individual elements, the human components, their respective interactions and impacts on human performance are properly understood and documented. The audience will agree that there are enormous challenges in this area beckoning to the world community of scientists for information.

In specific terms, the following are some of the challenges:

- Development of a systematic methodology to facilitate the process of scientific investigation of human work;
- Study to uncover how the elements in the respective work environments individually or in combination impact on human work performance;
- Examine how the interactions of work environmental elements impact on human performance;
- Generate valid scientific data on human body dimensions and structure; human capabilities and limitations as well as motion inventories;
- Determine environmental parameter values which provide a conducive environment for humans to work most efficiently, safely, effectively and sustainably.

Taken together, these tasks constitute the pure science of human work, recognized since the seventeenth century by Kroemer et al. (2001). However, it was only in 1949 that its native name, Ergonomics, was coined and defined as the "scientific study of man and his working environment" (Murrell 1965). He derived the name from two Greek words: *ergon* meaning work or effort and *nomos,* meaning laws. In America, it is called Human Engineering. Ergonomics is multidisciplinary with Psychology, Sociology, Anatomy, Physiology, Medicine and Engineering as body of knowledge contributors (Kroemer et al. 2007).

The Applied Science of Work

Conducive work environment is only one of the several determinants of human work performance. The worker has to have strength and creativity; be competent and intelligent to display high quality and speed of work; possess good leadership characteristics and compatibility to appreciate others; and, above all, have work integrity and prudence to avoid waste.

Having emotions, superior brain power, great potential for creativity, and being highly inductive and adaptive, humans can envisage and prepare to effectively deal with high-grade challenges even before they occur. However, the human skeletal structure is too fragile to carry out activities which require even moderate levels of forces. The sense organs are also not capable of sensing some levels of stimuli. Besides, the eyes, ears and skin, the external components of the sense organs which directly interface with the work environment are too tender. The human maximum aerobic power is not high enough to sustain him for long hours on large energy-sapping activities. Fatigue, an inevitable outcome of the metabolic process, limits his/her speed while human inconsistency in repetitive tasks restricts his/her quality of work. Also, anthropometric dimensions, general body structure and density limit its mechanical advantage, motion inventory, reach, and ability to move rapidly unaided on land, in air and at sea. Clearly, for speed, quality, safety, reliability, minimum cost and waste, humans need some specialized skills, knowledge and devices at work. It is in reflecting the reality that the human alone is grossly inadequate for large-scale work, that Barnes (1933) introduced the concept of *Man-Machine Work System,* a term extensively adopted by such work analysts as Bostrum and Heinen (1977), Summer and Ryan (1994), and Kroemer et al. (2000). Alter (1990) defined it as "a system in which human participants and machines perform work".

The man-machine work system may be as simple as a student sitting on a chair, writing or studying on a desk. It may as well be as complex as a large-scale factory or outer space exploration voyage. Work systems can be found in our homes, academic environment, agriculture, transportation, manufacturing, mineral exploration, communication, commerce, judiciary, to mention just a few.

Notice that the machine component of work system does not, on its own, come into existence and then bring about changes. The human, desiring rapid quality changes in his/her environment, envisions, develops and applies machines as technical aids. Machines are therefore subordinate to humans and not vice versa. Thus, an artisan will shape and sharpen a piece of metal and call it implement for farm work. Engineers identify and assemble several components and subsystems of processed entities and call the resulting system a vehicle, airplane or ship. In this case, it is an attempt to facilitate the work process of travelling. In other cases, a set of lenses are organized in accordance to some observed principles to obtain a microscope to enhance the human power to see and work with microscopic organisms. Thus, whether it is in evolving the atomic bomb, the computer, a drone, robot or internet system, the human is only being creative and adaptive to boost his capability to work and achieve greater changes. It thus appears safe to state that "man-machine work system is the major instrument for desirable change".

Charles-Owaba (2001) used a schematic diagram to portray the man-machine work system as the input-output entity in figure 3.

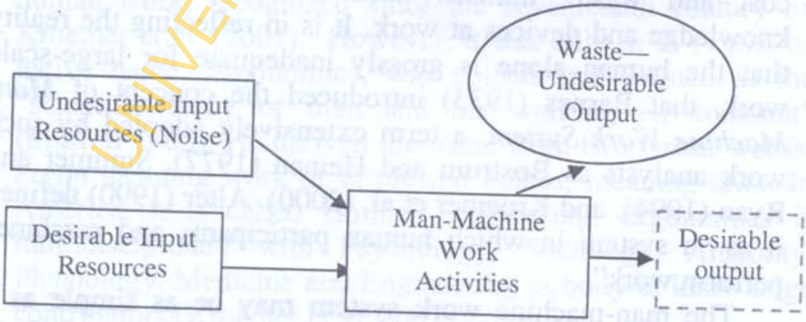

Fig. 3: Input-Output diagram of a work system

Note the two categories of input resources: **desirable** and **undesirable**. The same is true with the output: **desirable outputs and undesirable or waste**. Generally, inputs are knowledge, procedures and the basic resources: manpower, facilities, information, materials, energy and finance. The desirable inputs are the optimal quantities and qualities of each category of the required types of inputs supplied just in time. Other desirables are optimal personnel management structure, optimal personnel motivation system, optimal facilities maintenance system, quality management systems, and safety engineering systems.

Wrong types of inputs or right types but non-optimal quantities and qualities of the basic resources are undesirable inputs. Other undesirables include non-optimal systems or procedures for managing these resources while in storage or in process. Even when the quantities of input resources and their management systems are optimal, late or too early entry into the work system may generate waste in form of inventory. Some examples are personnel without experience or with irrelevant skills; excessive or too few number of personnel. Others include epileptic supply of power, finance, materials and information. Desirable outputs are the work system's originally intended products, services or utilities acceptable to customers. Popularly known as WASTE, the undesirables come from producing less than naturally expected from a given amount of input resources. This may mean either producing nothing at all, scraps, rejects, reworks, down-grades or death traps. Other indicators of waste are ineffective services, ineffective development policies, budgets that cannot develop a nation, dilapidated structures, abandoned projects, and tertiary institution graduates who cannot establish their relevance in a lifetime.

Work systems which produce mostly waste are said to be inefficient. Clearly, an organization with inefficient work systems rapidly decays and finally liquidates. It follows that a nation whose work systems are inefficient will inevitably experience high rates of business failures, corporate unemployment, poor salary scales, poor infrastructure, inadequate utilities, high prices of goods, and widespread poverty in the land. Clearly, whether it is an individual, a corporate body or a nation, desirable work output is a mark of progress or positive change while waste is the sign of backwardness. Hence, let it be noted that, to develop Industrially, to alleviate poverty and to check unemployment, a nation must cultivate an effective strategy to continually eliminate waste in all its work systems.

Knowledge of the root causes of waste in work systems may be useful for developing an elimination strategy. Waste enters a work system through

- design of the work system;
- design of machines and tools;
- type of work (negative and neutral work, for example);
- input resources;
- conflicts;
- quality of work;
- pace of work;
- accidents;
- condition of work facilities;
- feelings of an individual worker;
- corporate will;
- inventory of materials, in-process and finished goods, and spare parts;
- operations planning;
- operation processes including procedures; and
- corporate climate.

For illustration, feeding undesirable inputs into any work system; or desirable inputs into negative and neutral work, generates only WASTE. Only the use of desirable inputs in positive work reduces WASTE. The war on global competition will be won by nations that evolve the most effective strategy to continuously curb waste at work

(Womack et al. 1990, MIT). Perhaps, this is the motivation for the heavy expenditures on research for new production technologies by the advanced nations. Only a well researched and developed strategy may be effective.

On close examination of the listed waste-fermenting factors of work, it is clear that only a scientific approach to work systems design, analysis, synthesis, installation, operations planning and control can provide an effective waste eradication strategy. To gain understanding and competence in this business, knowledge of the following is essential:

- Ergonomics;
- Machine and material processes;
- Human process optimization principles and practices;
- Portfolio selection and replacement principles;
- Reliability and maintenance processes;
- Tooling, automation and robotic processes;
- Quality evolution and control processes;
- Hazard identification and control processes;
- Facilities location and layout processes;
- Operations systems design processes;
- Inventory systems design and control processes;
- Performance management systems design processes;
- Ambient environmental conditioning principles;
- Concurrent engineering processes;
- Individual or group decision systems design;
- Cellular and flexible work process design;
- Activities scheduling and sequencing processes;
- Supply chain processes;
- Measurement and control principles and practices;
- Work waste identification and elimination processes;
- Production planning and control processes;
- Inference statistics and simulation processes; and
- General optimization and operations research principles and practices.

Fortunately or unfortunately, one may not appreciate or apply these tools and processes without first acquiring appropriate levels of mathematical and graphic languages; understand the combined principles of the systematic, physical and social sciences. Observe that these are the requirements for a subject to be called an Applied Science. Hence, these languages, principles and the afore-listed constitute the body of knowledge called Applied Science of Human Work. Its roots can be traced to Ergonomics and Physics the same manner Mechanical Engineering is an Applied Science derived from aspects of Physics, and Electrical Engineering in the theory of Electricity and Magnetism, and Chemical Engineering from Chemistry. Known as INDUSTRIAL ENGINEERING, the areas of knowledge which combine to form this pearl of human-based engineering is shown in figure 4.

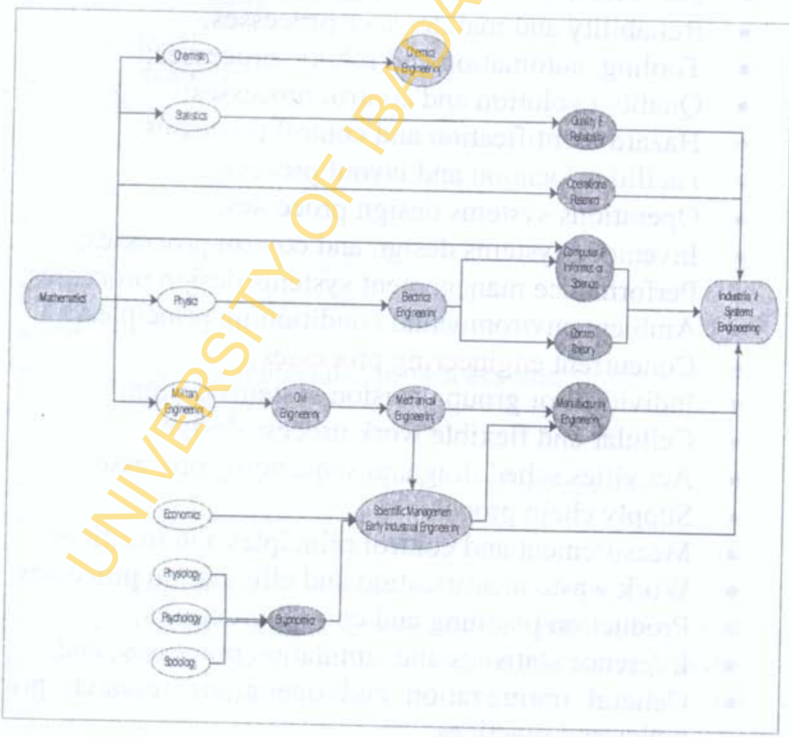

Fig. 4: Roots of Industrial Engineering (Adapted from Turner et al. 1993)

Historical Perspective

Recalling the definition of work, it is apparent that the story of work is the account of how man faced challenges and his struggles to overcome them, his discoveries and inventions that enabled him, not only to survive but also conquer natural constraints through diligent and intelligent work. Indeed, it is the history of how the vessel of civilization discriminately travelled from one shore to another, with man as the driver and machines, his power source in an attempt to change the world. As to the manner of this journey, I totally agree with the observations of Womack et al. (1990) who said: "How we make things dictates how we work, how we think and how we live." Implicitly, Womack was referring to the man-made tools, machines, air-conditioners, displays, controls, illumination, and material handling devices, furniture and sensing aids, the elements of man's immediate work environment mentioned earlier. In part, these dictate the pace of human performance. Observe that the absence of these elements at the workplace implies turning the civilization clock to the early-man mode of working, thinking and living.

It therefore appears safe to say that the history of work cannot be complete without mentioning the great discoveries/inventions of electricity by William Gilbert, a Briton, in 1550; the steam engine by James Watt, another Briton, in 1764; and the light bulb by Thomas Edison, an American, in 1879. Thus, steam and electrical power, among others, increased man's potential to apply higher forces, exercise more effective controls and work longer hours with higher precision. Others include the inventions of the air-conditioner by a German Engineer, Carl von Linde, in1876 and the heater by Edwin Rudd, a Norwegian, in 1889. These allow the control of heat and cold for the safety and comfort of the worker. However, work in businesses which require long distance travels or communication are rife with enormous waste of man-hours, money, time and agonizing moments through perils. This must have aroused Mother Nature's sympathy for mankind as Alexander Graham Bell, an American, was inspired to invent the telephone in 1876; radio was invented by Thomas Edison in 1885; television by Rosing, a Russian, in 1907; the cell-phone by Martin Cooper in 1973 and the internet by Vinton Cert and Bob Kahn, all Americans, in the same year.

Despite these epoch making contributions to the human work environment, Womack et al. (1990) observed that no invention has changed the way humans think, work and live more than the automobile vehicle invented in 1769 by Nicolas Cugnot of France. It triggered the race to capture the lion share of this world's largest industry through highly creative design and control of man-machine work systems. America took the lead by replacing the traditional European craft production and assembly system with mass production at about 1910. Klemm (1964), a technology historian, traced the origin of mass production to Whitney's principle and practice of interchangeable manufacture, Ford's manual assembly line system, and Sloan's shared-authority management principles. Through this, America captured about 50 percent of the world auto industry at about 1930 and retained it till 1955. While Europe was still trying to catch up with the Americans, at about 1948, the Japanese came up with the lean production system with monumental achievements in waste reduction, high rate and quality production as well as service delivery. Womack et al. (1990) observed that the lean system sliced waste off automobile manufacture by about fifty percent. This left both the American and European auto industries gasping for economic breadth till today. Perhaps, this explains why one Japanese quality-related error is worth more than one thousand life-time news items.

Meanwhile, work under water and in air environments was made feasible by the inventions of the submarine by Drebbel (a Scottish) in 1620 and the airplane by the American Wright brothers in 1903. Having witnessed these great inventions and the impact on human work performance, some great philosophers were aroused not only to advocate for the applied science of work but they also searched for the tools and, in some cases, demonstrated its potentials. One of the pioneers was none other than Adam Smith, the father of Economics who, in 1776, advocated the scientific approach in the design and management of manufacturing work systems. He demonstrated the importance of the division of labour in productivity improvement. In 1832, Charles Babbage, the famous Professor of Mathematics and inventor of the computer added his voice in calling for further segmenting labour into mental and physical components for a better remuneration system. He added that human work should be measured arguing in his book; *On the Economy of Machinery and Manufactures* (1832) that "only what is measured can be controlled". In 1886, Towne, a Mechanical Engineer published a paper in the *Economist*, calling Engineers to accept and apply engineering tools, principles and procedures to work systems design, analysis and synthesis.

At about 1900, Frank Gilbreth and his wife, Lillian, established that, in any given work situation, there is "one best way" to work. The corollary is also true: there is also "one worst way" to do any work. This theory implies that if work is carried out in the "one best way", then the highest volume and quality of output will be attained with minimum time and resources. It follows that adopting the "one worst way" will result in the lowest quantity and quality at maximum time and resources. Deductively, in between these two extremes ("one best way" and "one worst way") are other ways with intermediate results. Clearly, until one finds the "one best way", there is always a better way to work. Earlier, Fredrick Taylor, also an American, established that human work is designable and measurable and then went on to demonstrate that workers can be scientifically induced or motivated to find and follow the "one best way" of work for greatest returns. This is the theoretical basis for human performance management popularly known as Fredrick Taylor's principles of scientific management. Based on this, the first department of Industrial Engineering was established in the University of Syracuse, USA in 1908.

The huge successes of the 18th century application of scientific management spurred many to search for graphical, mathematical and statistical tools for work systems design, analysis and management. The post-Taylor hero, Harris (1915), was the first to develop and apply a mathematical model for searching, identifying and eliminating the latent waste (cost) inherent in inventory systems (see fig. 5).

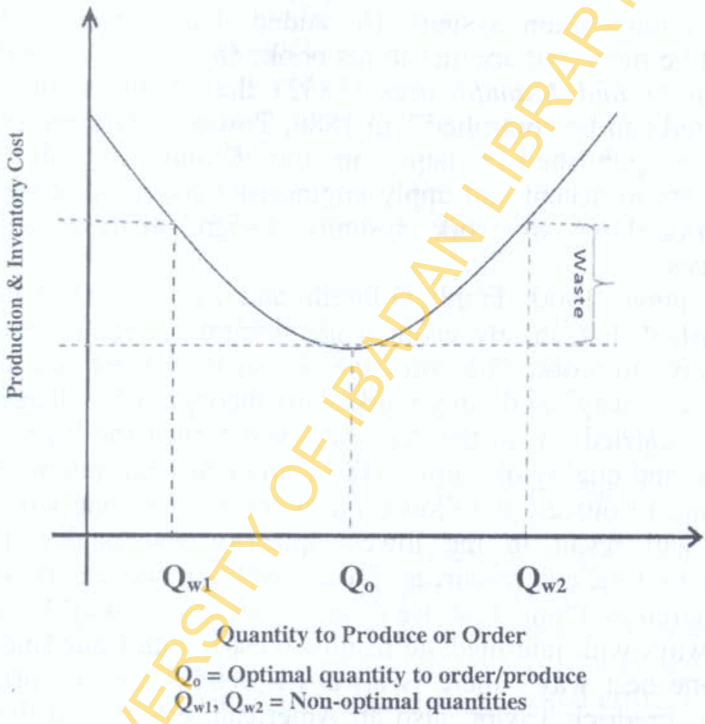

Fig. 5: Harris graphical example of Mathematical Decision Model

Henry Gantt followed suit by introducing the Gantt chart for operations scheduling and control. Shewhart (1931) formulated the highly celebrated Statistical Quality Control model that reduced the effort to control product and service quality by more than 70 percent. In the same year, Bell Company of the United States introduced engineering economic mathematical models for searching and eliminating waste in portfolio selection and operations. DuPont, another US corporate entity, introduced the Critical Path Methods (CPM), and the US Navy, the Project Evaluation and Review Technique (PERT) for project management, and Tippet (1934), a Briton, introduced the discrete event simulation tool for work system design and analysis.

However, one drawback of Taylor's scientific management approach was his overemphasis on the individual at the expense of team dynamics in corporate work. Mayo, in1923, in elaborate experimental studies, established the importance of group dynamics at the workplace. A few years later, the Japanese became the first to tap the value of Mayo's work in their celebrated small groups called Quality Circles. Ever since, the search for dramatic waste eliminating, time saving, cost reduction and customer satisfaction team-based work management strategies have been on the increase. There are the team motivation techniques, worker empowerment, and respect for the autonomy of the individual strategies. Others include Supply Chain, Learning Organization, Total Quality Management, Business Process Re-engineering, and Concurrent Engineering, all being components of horizontal management as distinct from the traditional vertical approach.

Even more remarkable was the post-World War II work of Dantzig (a Jew), who fine-tuned the Operations Research mathematical modelling and solution methodology (initiated by the British Navy during World War II) for searching, identifying and eliminating all forms of waste parameters in work systems. Notice that this allows the work system designer to, *a priori*, optimally determine all desirable work input parameters including the number, management structure and caliber of the human resource, facilities, information, energy, materials, finance, space, and appropriate location of an enterprise. Nature was not done yet in preparing mankind to celebrate the birth of a great profession for nations who will love rapid industrialization. At about 1948, Forrester was inspired to introduce Systems Dynamics mathematical modelling methodology for complex time-based work systems design decisions.

It was at this stage that corporate entities, worldwide, could no longer hoard the powerful tools, and creative principles for design, analysis, synthesis, operation, control and installation of man-machine work systems for maximum safety, quality, speed of work and minimum cost of goods and services. In 1948, academic and practising engineers gathered in New York to form the professional body of Applied Science of Human Work known as American Institute of Industrial Engineers (AIIE). Later shortened to Institute of Industrial Engineers (IIE), it is the world's apex professional body which regulates Industrial Engineering. It is also noteworthy that the University of Ibadan, being the first to bring it to Africa, South of the Sahara in 1980, is just being the usual pacesetter of innovative concepts. As to the obvious question of why Nigeria is still a toddler in industrial development after these years, we should remember that she/he who purchases pretty cloths but decides to ignore them in a wardrobe will certainly go shoddy.

My Humble Contributions

My first six years at the University of Ibadan were devoted exclusively to preparing the ground and sowing the seed of this important Applied Science, an inevitable situation brought upon me by brain drain. One morning, I found myself as the only head and tail with the full academic and administrative workload of 97 BSc, 22 MSc, and one PhD candidates in the department of Industrial Engineering. Other academic staff had left for greener pastures. Though the most trying period of my career, today I recall with enormous joy; the department survived and yielded juicy fruits as the only PhD student then is today the Dean of the Faculty of Technology. I am, therefore, very happy to announce to this great audience, that I am the only father in Nigeria today with his academic son as the boss.

It was only in 1988, that my journey for personal research commenced. The focus has been the development of models for identifying optimal value of work system input parameters which would eliminate waste, improve quality, and minimize cost while maximizing output. In the following are some of the work situations and the associated waste elimination models.

Machine Parts Manufacturing Systems Design

For many years, a complex flow pattern and machine set-up requirements precipitated an enormous production waste problem in machine parts manufacture and assembly. Confirming the problem, Merchant (1975) observed that in-process machine parts spent about 98% of production time either waiting for machines to be set up or move from one machine/department to another. Mitrofanov (1966), a Russian, proposed a Group Technology (GT) manufacturing system in which all components with similar machine set-up requirements are processed in one cell. The world community was however skeptical for lack of theoretical basis supporting the claim. In response, Charles-Owaba and Lambert (1988) formulated a mathematical model which established a quantitative relationship between set-up tasks and machine part's design characteristics using the concepts of Boolean algebra, binary interaction matrix, and similarity vectors. The first of its type, the model quantitatively related machine set-up cost to similarity of parts. With it, it was feasible to demonstrate theoretically the popular Group Technology goal of machine set-up and parts' transportation cost reduction. A decade later, Charles-Owaba (1998a, 2002c) used the Operations Research framework to define and characterize the GT grouping problem as well as proffer an algorithm to efficiently solve it. The power of this procedure to simplify machine parts flow pattern thereby bring order to an otherwise chaotic production situation is illustrated in figures 6 and 7.

PARTS	1	2	4	5	6	8	9	11	14	15	16
	MACHINES										
2		X			X	X	X		X		X
4							X				
5			X	X						X	
6				X	X	X					
9			X	X		X		X			
10		X					X				X
14			X	X	X					X	
15			X								
16				X							
18					X		X				X
19			X			X				X	
21			X			X				X	
23			X	X	X	X					
28		X				X	X				
29			X	X							
32		X			X	X	X				X
33				X	X					X	
37	X	X			X	X	X				X
38		X				X	X				X
40		X			X		X				
41				X		X				X	
42	X	X			X		X				X
43				X	X	X				X	

Fig. 6: Machine Parts Conventional Manufacturing System

PARTS	4	5	8	15	6	11	2	6	9	16	1	8
	MACHINES											
21	X	X	X	X								
5	X	X		X								
14	X	X		X	X							
19	X	X	X	X	X							
29	X	X										
23	X	X	X		X							
9	X	X	X			X						
41		X	X	X								
43		X	X	X	X							
33		X		X	X							
6		X	X		X							
16		X										
15		X	X									
32							X	X	X	X	X	
42							X	X	X	X		
10							X		X	X	X	
37							X	X	X	X		X
38							X		X	X	X	X
2							X	X	X	X		X
40							X	X	X			
28							X		X			X
18									X	X		
4									X			

CELL 1

CELL 2

Fig. 7: Machine Parts Cellular Manufacturing System

Notice in this example that by replacing the conventional system with two manufacturing cells in which parts using the same machine set-up are processed in one and only one cell, production waste arising from excess time spent resetting machines and parts' transportation was eliminated. Further still, Charles-Owaba (1998b) proposed a mathematical model for determining the optimal personnel team size for manning cellular manufacturing systems. These are some of the waste elimination models that provided the theoretical basis for the design of cellular and flexible manufacturing systems.

Machine Set-up Problem

A twin issue in machine parts manufacture and assembly is the problem of determining the processing sequence of a batch of N parts by a general purpose processor. This machine set-up problem (MSP) has been identified as belonging to a family of problems known as NP-Hard for its computational complexity (Karp 1974). The traditional solution approach has been to implicitly enumerate and select the optimal from among all N! permutation sequences. Consequently, computation time grows exponentially with problem size (N) to the extent that super computers could not solve large industrial problems. Indeed, Cook (1998) asserted that "no polynomial algorithm has been found for it till date". Charles-Owaba (2002b) proposed a set sequencing theory which established sufficient and necessary conditions for optimal solution. Based on this, a set sequencing optimal solution procedure with a polynomial computation time curve of degree 4.5 was developed. In 2007, Oladokun and Charles-Owaba refined the algorithm thereby drastically improving the time curve to a polynomial of degree 3.5, the lowest ever reported. The effectiveness of applying set sequencing algorithm to iteratively search and eliminate waste is illustrated in figure 8.

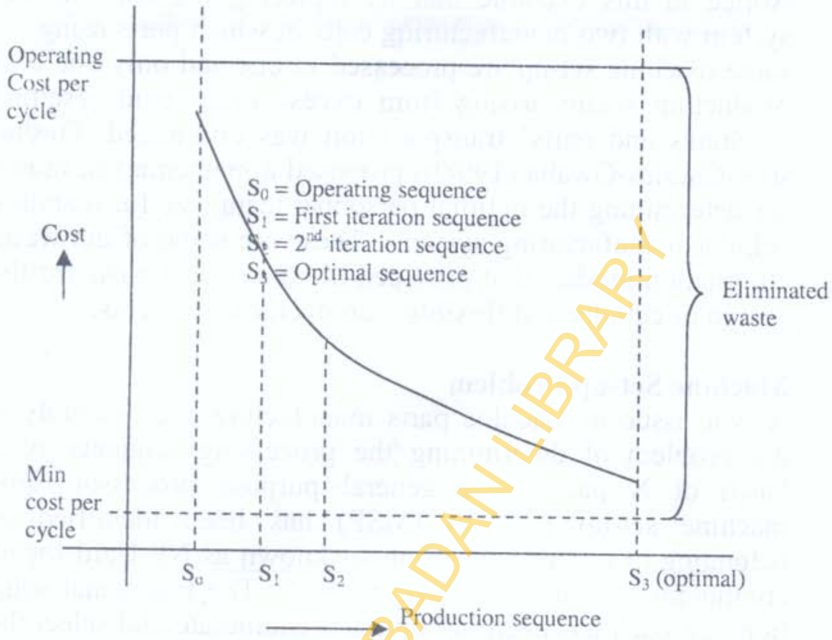

Fig. 8: Set sequencing waste elimination graph

Further extending the set sequencing theory, Charles-Owaba (2001a, 2002c, 2002g) established a mathematical framework for identifying subsets of special problems within a larger GT scheduling problem such that by solving each of these smaller problems, the parent problem is implicitly solved. This important decomposition algorithm was applied to split and solve a real-life problem of twenty three parts into three smaller ones. Extending the same theoretical concept, Charles-Owaba (1998d) defined and solved a sequence-dependent machining parameter selection problem with significant reduction in operating time as shown in figure 9.

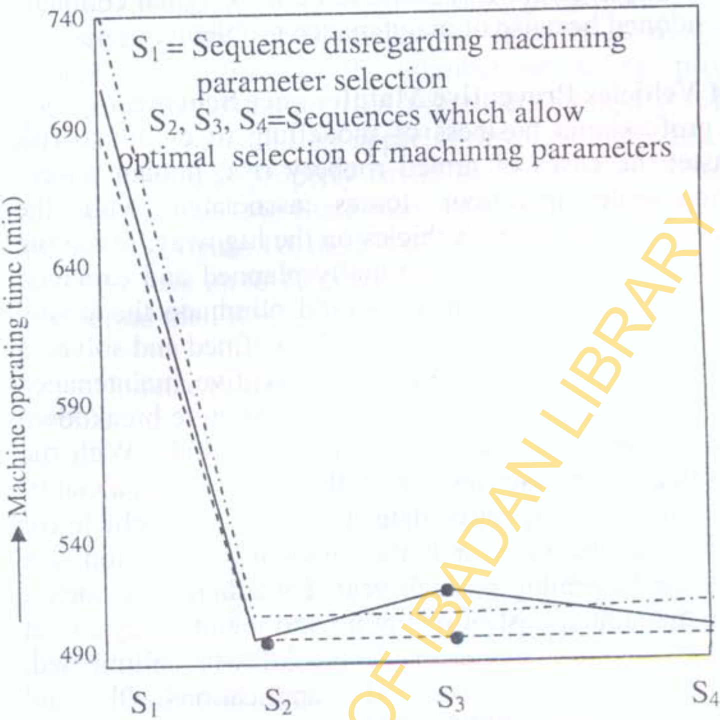

Fig. 9: Graph of processing time versus production Sequence-based (S_i) machining parameter selection

Quality Management

Choice of quality level for any in-process product/service is another important waste-generating activity. A study by Charles-Owaba and Jegede (1988) revealed that associated with controllable process-quality are two very stubborn variable components: quality control and quality failure costs. An attempt to drastically reduce waste through one increases quality cost through the other. In another study, Charles-Owaba (2004c) derived a polynomial quality cost function in terms of product quality level, quality control and failure parameters. Based on this, a non-linear optimization problem was defined and a procedure for determining optimal quality level which eliminates quality-related waste was developed. The validity of this result was satisfactorily tested in a cigarette processing plant. A zero-defect quality policy derived with the model was found to be the original company plan abandoned because of maintenance problems.

Fleet of Vehicles Preventive Maintenance Scheme

In our professional business of modelling to eliminate risk and waste; the cases of armed robbery risk, human misery and large-scale man-hour losses associated with the breakdown of commercial vehicles on the highway, in remote areas, deserve mention. An optimally planned and executed preventive maintenance scheme would eliminate the waste, risk and misery. Charles-Owaba (2002a) defined and solved a resource-constrained Gantt-charting preventive maintenance scheduling problem in terms of vehicle predictive breakdown date, maintenance duration and operation periods. With the model, a fleet of vehicles are optimally scheduled on a Gantt-chart such that the respective dates to return each vehicle for preventive maintenance and the associated duration are known at the beginning of each year. By adhering to such a schedule, the annual cost of operating and maintaining a fleet of vehicles is minimized and breakdowns eliminated. Examining this principle for wider applications, Oke and Charles-Owaba (2005, 2006a, 2006b) carried out extensive sensitivity analysis under different shipping situations and showed that elimination of an annual waste worth millions of naira per ship is feasible.

Work System Safety

Workplace hazards are some of the factors responsible for large amounts of waste through losses of limbs, lives, skilled personnel, equipment, man-hours and machine-hours, due to accidents. Unfortunately, business owners hardly accept this reality for two reasons. One, scientific models for measuring the exact safety level of a work system are sparse. Secondly, there are several national and international agencies demanding for occupational safety programmes whose benefits even the agencies are unable to verify.

To ameliorate the situation, Charles-Owaba and Adebiyi (2001b) were the first to combine the principles of statistical expectation and productivity to develop a mathematical model for estimating the number of safety programme prevented accidents and the associated monetary value. The model was validated by applying it to estimate the value of lives, limbs and property saved by the Federal Road Safety Commission of Oyo State from 1988 to 1997. Summarized in table 1 and figure 10, the FRSC exhibited steady performance improvement up to 1995 with a significant decline from 1996, the period the FRSC – POLICE conflicts commenced.

Table 1: Oyo State FRSC Road Safety Programme Performance Data

Year	Estimated number of prevented accidents				Value of lives & property saved (N) x 10^6	Safety effort (N) x 10^6	Safety efficiency index	Gain (N) x 10^6 due to efficient operation
	Fatal	Serious	Minor	Total cases				
1979	308	413	850	1561	306.438	6.232	-	-
1988	373	600	636	1609	374.512	1.664	2.3742	2.286
1989	353	562	645	1560	354.776	2.405	3.0003	4.810
1990	309	44	497	846	245.835	2.652	1.8850	2.247
1991	365	807	316	1488	389.084	3.663	2.1601	4.249
1992	501	843	778	2122	561.183	5.176	2.0004	5.178
1993	500	928	854	2282	519.436	5.173	2.0421	5.390
1994	585	908	894	2387	579.943	8.015	1.4738	3.797
1995	600	1009	882	2491	604.783	6.489	1.8952	5.809
1996	585	946	866	2397	584.523	10.257	1.1589	1.630
1997	462	685	628	1775	451.396	10.857	0.8435	-1.678
TOTAL	4183	7332	6996	18551	4610.498	56.851	-	33.818

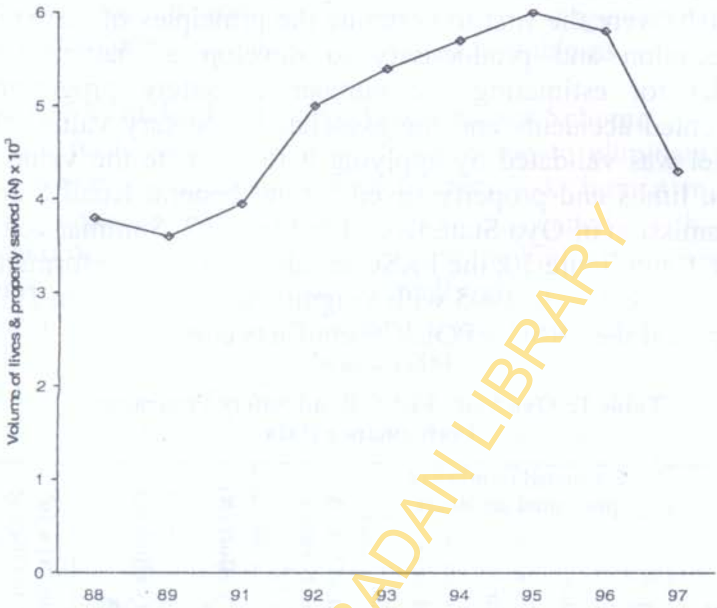

Fig. 10: Value of lives and property saved (₦)

Notice that in the first decade of operation, the agency prevented 4183 fatal, 7332 serious and 6996 minor accidents in Oyo State. These translated into 4.6 billion Naira worth of lives, limbs and property saved on the highways, a clear case of national waste elimination.

Charles-Owaba (2001d) developed a general stochastic function for quantifying the safety level of any human-controlled work environment. The accident proneness of each system component and the associated severity are the model parameters while controllable hazardous state, the variable. Based on this, Saf, a unit of safety, was introduced, a safety measuring procedure was proposed and the feasibility of applying in real-life situations demonstrated on a 504 Peugeot (private car) and a 160K Datsun (commercial car). The maximum possible safety level of a saloon car was found to be 529.78 Safs; the first vehicle has 411.11 Safs (20% unsafe) while the second has 266.24 Safs (50% unsafe) as shown in table 2.

Table 2: Vehicle Safety Evaluation Data

Vehicle Type	Max. Possible Safety Level (Safs)	Measured Safety Level		Measured Unsafe Level (Percentage)
		SAFS	Percentage	
504 Peugeot Saloon (Private)	529.78	421.11	80%	20%
160K Datsun (Commercial)	529.78	266.24	50%	50%

Still searching for accidents-related waste elimination, Charles-Owaba and Adebiyi (2006) applied the principles of system dynamics to formulate an exponential function for predicting the periodic number of experienced accidents. It was formulated in terms of workplace hazards, amount of exposure and environmental risk of accidents. Also defined in terms of safety programme implemented budget and the measure of effectiveness of safety programme training, incentives, awareness activities, use of personal protective devices; accident investigation, and facilities guarding are functions of the number of accidents prevented. Combining both functions and adding the accident cost parameter, a safety programme cost performance measure was derived and applied to solve a bottling company problem. It was demonstrated that if the model-recommended safety programme variable values were adopted, a total annual waste of 4.6 million naira would be eliminated through accident prevention.

Low Back Pain (LBP)

Murphy et al. (1996) reported that low back pain (LBP) represents a major health problem with well over 15 billion dollars expended annually on treatment and compensation in the United States alone. It may be noted that this is a good example of hazard-related waste. Anderson et al. (1974) observed that manual load lifting is responsible for about 75% of cases of LBP, the source of agony to many workers and heavy losses to industry. In the past four decades, several attempts were made to find a safe weight a worker can lift, lower or carry to avoid LBP. The most celebrated model was the 1991 NIOSH Equation which has a serious drawback because it neither includes the lifter's body dimensions nor LBP-linked parameters (Waters et al. 1993). Consequently, the NIOSH model was not useful for matching the individual worker to industrial tasks for quality, higher productivity and safety. In the search for a better model, Ismaila and Charles-Owaba (2008a) established that a worker is shorter after physical work than after prolonged rest. Using this observation, Ismaila and Charles-Owaba (2008b, 2008c) applied strain energy principles to develop a mathematical function for computing the load an individual can safely lift in terms of the lifter's spinal length (L), chest frontal length (l_f) and side length (l_s). Other parameters of the function are lifting task characteristics, critical spinal disc strain (ψ_c), Young's Modulus of spinal disc cartilage (E) and acceleration due to gravity (g). Hence, for a known lifting task, an individual can determine the maximum weight he can safely lift or carry. An organization can also use the model to select and match workers and tasks for safety, quality and productivity.

However, the assignment of tasks without due consideration for stature may also trigger waste. An example is assigning a worker with short reach to operate a control panel too high for him. To provide information for productive matching of personnel to different tasks, Kolawole, Charles-Owaba and Ajisegiri (2009), reported anthropometric data showing that Hausa males are taller; have larger overhead reach, popliteal and sitting heights than their Yoruba counterparts.

Project Selection and Management Models

Kerzner (2000) reported that project-based management style is now the most effective work system waste elimination instrument because of its power to successfully integrate team building, risk management, total quality management, change management and concurrent engineering. Besides, it encourages the use of mathematical, statistical, simulation, artificial intelligence and other IT tools for more accurate technical planning. One important task in technical planning is project network diagramming. Anyaeche, Charles-Owaba and Oladipo (2009) proposed a backward-pass algorithm for simultaneous identification of project activities, precedence constraints and the associated network.

Another project planning issue is the problem of selecting feasible and economically viable projects. Charles-Owaba and Popoola (2002) formulated a stochastic mathematical cost function in terms of power failure, power generating and transmitting parameters for optimal selection of electric power supply sources. Applying to a choice between NEPA, Diesel Generator and Steam Turbine for a ten-year energy supply in a paper mill factory, it was shown that the Diesel generator is seven times and NEPA six times more expensive than Steam turbine (see table 3).

Table 3: Summary of Equivalent Annual Costs for the Three Alternatives

Year	Diesel generator cost	NEPA cost	Steam turbine cost
1	360,030,199	351,452,848	66,074,712
2	390,840,134	351,250,570	64,815,757
3	393,136,437	350,767,410	63,634,832
4	416,707,396	370,558,830	66,132,270
5	395,696,247	349,908,520	61,553,493
6	397,088,290	349,676,670	60,601,275
7	398,697,832	349,520,110	59,743,812
8	400,160,194	349,249,490	52,922,462
9	401,812,897	349,100,670	58,184,373
10	403,266,504	347,680,960	57,469,510

Similarly, Charles-Owaba and Abdul-Hameed (2002), modelling multiple project materials importation under storage restriction, reduced inventory cost by 2.25 times while Adeyeye and Charles-Owaba (2008) applied an optimization model to improve facilities utilization by 43.8%.

Organizing People to Minimize Waste

The manpower resource is yet another input parameter capable of generating enormous amounts of waste. Charles-Owaba (2002f) showed that, for a given volume of any business, private or public, there exists an optimal number of personnel which will produce the desired output with minimum cost and redundancy. An associated management structure will indicate the optimal number of lowest level personnel (N_0); number of supervisors (N_s); number of management levels (L); and number of managers (M). To deploy less than the optimal would mean waste through idle facilities while more translates into waste as personnel redundancy cost. Unfortunately, up to the 1980s, quantitative procedures for attaining this highly desirable optimal manning of an establishment were lacking (Hax and Majluf 1981; Peter Drucker 1974). Consequently, Charles-Owaba (1986, 1987) applied the principles of human dynamics to formulate a personnel redundancy mathematical function and showed that span of control (K) is the most critical organizational design variable as illustrated in figure 11.

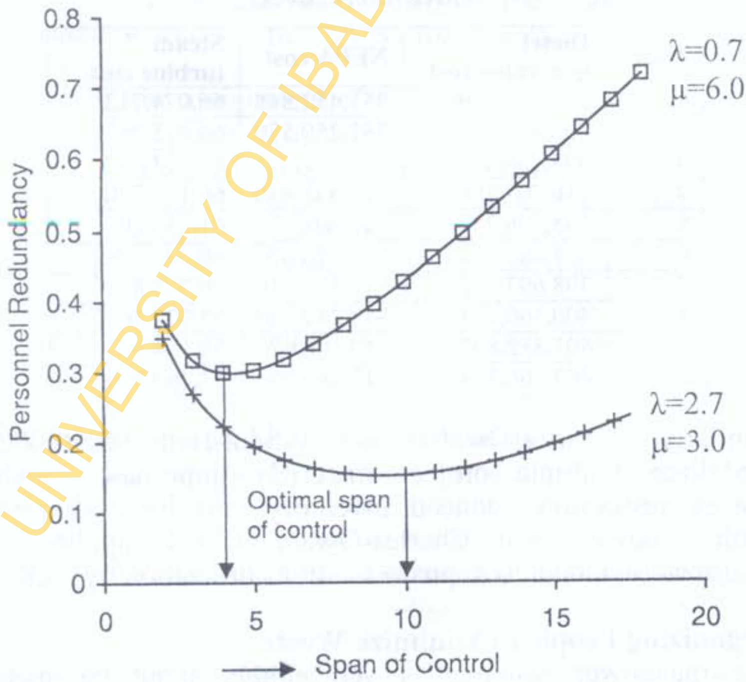

Fig. 11: Personnel redundancy versus span of control (K)

Notice that choosing span of control other than the optimal implies waste. It was also observed that subordinates consultation (λ) and the superior attending (μ) rates are the important design parameters. Charles-Owaba (2002d, 2002f) also identified organizational design elements, proposed and applied the six design principles presented in table 4.

Table 4: Summary of Design Principles and the Related Theories

S/No	Design Principle	Operational Meaning
1	Fixed workload per personnel	Standard workload for every personnel
2	One-boss structure	A management unit has only one head
3	Hierarchical decision levels	Higher level positions have higher authority
4	Human dynamic interactions	Dynamic interaction takes place between superior and his subordinates
5	Interconnected sets of management units	There exists multiple management units, which are interconnected through communication lines
6	Situation-dependent structure	Design data are to be collected from the activities of the establishment.

Based on these principles, Charles-Owaba (1998, 2002) formulated a general personnel redundancy function:

$$R = \phi(K, N_s, M, L; \lambda, \mu, N_o)$$

Using this as an objective function and adopting the Operation Research paradigm, the organizational design problem was defined, and an optimal solution procedure proposed and tested to redesign one Nigerian civil service division. The summary in table 5 shows that, by adopting the newly designed structure, there would be only 15 management positions instead of the 76, and personnel redundancy of 1.63% instead of 80.26% in the existing structure. This would lead to an elimination of N44,072,640 worth of annual waste.

Table 5: Difference between Existing and Newly Designed Organization Structure

Items	Existing Organization Structure	Designed Organization Structure	Difference
Number of management/supervisory staff	76	15	+61
Number of management levels	6	3	+3
Number of lowest level staff	147	101	+46
Personnel redundancy	80.26%	1.63%	+78.63%
Annual emolument (1993-rate)	N66,340,080	N22,267,440	+N44,072,640

Student-Teacher Ratio Problem

Also applying the human dynamic principle in an academic environment, Charles-Owaba (1998e) formulated an exponential learning-teaching man-hours utilization function:

$$H = \psi(K, t_1, t_1, t_1, D, y, \alpha, \lambda, \mu, t_4)$$

in terms of the number of students (K) per lecturer; total hours scheduled for lecturer's formal activities per week (D); proportion of official hours for student consultation (t_1); proportion of official hours for research and community service (t_2); proportion of official hours scheduled for assessing student work (t_3); weekly hours per course taught (y); number of courses assigned to a lecturer per semester (α); rate at which students consult lecturers for counselling, clinical work, tutorials, etc (λ); rate at which a lecturer attends to students (μ); and standard hours a lecturer needs to assess the work of a single student in a week (t_4).

Observe that K : 1, the student-teacher ratio, is the only variable of the function; t_1, t_2, t_3, D, y and α are university policy parameters while λ, μ and t_4 are specific course-related parameters. For instance, teaching courses which require a lot of one-on-one student/teacher contact may result in large values of student consultation rate (λ) but smaller, otherwise. Also, for a difficult course, a lecturer may spend ample time to explain to a single consulting student. In this case, (μ), the number of students a teacher can attend to per hour may be low. Similarly, values of t_4 will be high for examination scripts that are difficult to mark. Taken together, λ, μ and t_4 reflect, to some extent, teaching-learning complexity of a course. Using this function, the student-teacher ratio problem was defined and solved as that of selecting the optimal ratio which maximizes the teaching-learning situation. Overloading the teacher wastes student learning hours while underloading wastes teaching man-hours (see fig. 12).

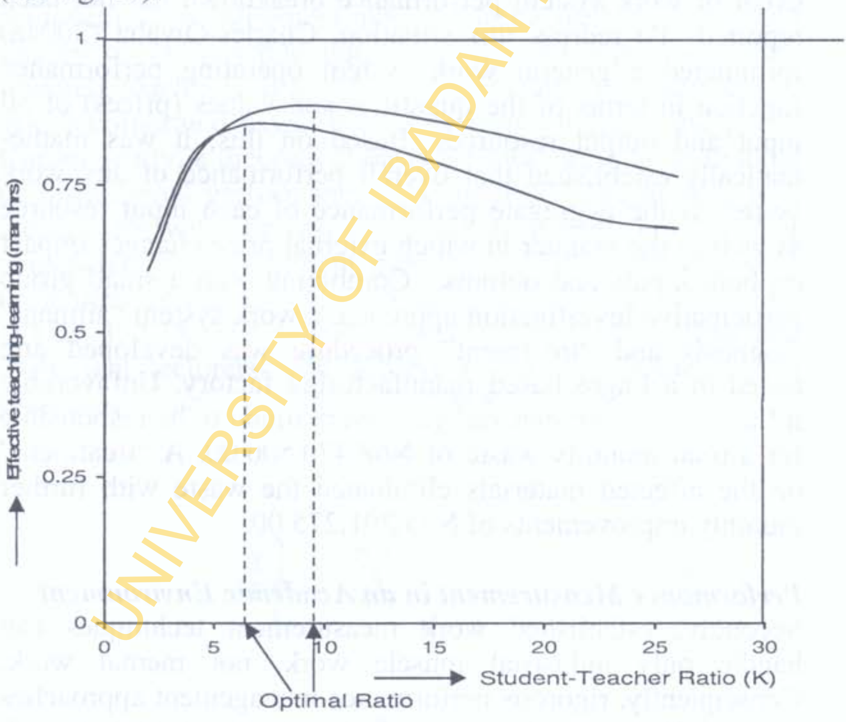

Fig. 12: Effective teaching-learning man-hours versus Student-Teacher ratio

Performance Management System

Observe that the aforementioned models are for work system waste elimination through optimal selection of input parameters. At the man-machine processing stage, waste is eliminated through what Groover (2007) refers to as the 3-Ms: **methods** (choice of "one-best way"); **measurement** (scientific targets setting and achievement verification); and **management** (align individual worker's will to the corporate will). Important as these fundamentals are, there are several unresolved issues in application.

Performance Diagnosis

First, a general systematic procedure for diagnosis in the event of work system performance breakdown has not been reported. To redress this situation, Charles-Owaba (2004a) formulated a general work system operating performance function in terms of the quantities and values (prices) of all input and output resources. Based on this, it was mathematically established that overall performance of any work system is the aggregate performance of each input resource as well as the manner in which external price changes impact on both inputs and outputs. Combining with a small group participative investigation approach, a work system "ailment" diagnosis and "treatment" procedure was developed and tested in a Lagos-based manufacturing factory. Unfavorable inflation and poor material yield were found to be responsible for a total monthly waste of ₦68,470,506.00. A "treatment" on the affected materials eliminated the waste with further monthly improvements of ₦35,391,275.00.

Performance Measurement in an Academic Environment

Secondly, established work measurement techniques can handle only industrial muscle work, not mental work. Consequently, rigorous performance management approaches have not been extended, in a holistic manner, to workers with predominantly mental activities worldwide. Typical of this category are lecturers. The current-state-of-the-art in university performance management appears grossly inadequate particularly for professional disciplines. The training of engineers, medical doctors, lawyers, accountants and journalists, for example, is a very serious business which may need a balanced pursuit not only in research quality but also in the other university functions. The over-reliance on only research publications for promotion decisions may well be at the expense of such good training essentials as properly designed and pursued continuous assessment schemes, small group demonstrations, tutorials and one-on-one counselling. Lecturers may be seriously tempted to pay no attention to activities not directly tied to their progress. To provide a basis for more comprehensive university performance management, Charles-Owaba (1994, 2004b) formulated a lecturer's achievement measurement model in terms of the quantity and quality of all possible outputs from, and input costs into research, teaching, administration, and community services. It also incorporated assessment data from students and peers. Consequently, a theoretical basis for measuring an individual or institutional performance was suggested and applied to a Department with the results shown in table 6. For the year considered, the department grew by 4.59%, and judiciously used their resources to attain all goals with a surplus of N122, 322.14. The model correctly identified efficient and inefficient lecturers, and achievers from non-achievers, as presented in table 6, columns 1, 7, & 8.

Table 6: Summary of Departmental Performance Data

Teacher (1)	Status (2)	Output (ACADA)		Input (money)		Performance	
		Target (3)	Actual(4)	Budget (₦) (5)	Actual Spending (₦) (6)	Percentage growth (7)	Efficiency (₦) (8)
Emma	Lecturer II	577.79	426.14	193767.68	170106.26	-15.99	-27195.94
Miki	Lecturer II	577.79	524.80	193767.68	175694.12	+0.05	+81.47
Timi	Lecturer II	577.79	580.45	193767.68	184200.35	+5.88	+10459.37
Sandra	Lecturer I	847.24	849.50	242209.60	235126.28	+2.74	+6438.93
John	Lecturer I	847.24	876.06	242209.60	190690.46	+31.33	+59743.32
Martha	Lecturer I	847.24	869.30	242209.60	206245.18	+20.50	+42270.94
Angela	Lecturer I	847.24	798.70	242209.60	215200.08	+4.91	+10559.93
Nadum	Associate Professor	1016.69	1144.32	290651.52	254321.51	+28.63	+72816.88
Samson	Professor	1059.05	998.45	314872.48	315416.63	-5.38	-1851.51
Tony	Professor and dept. head	1059.05	1167.30	318995.65	300006.11	+17.20	+51595.42
Departmental total		8259.32	8235.02	279365.5	2663113.80	+4.59	+122322.14

Performance Management in the Civil Service

Another case in Nigeria with difficulty of applying rigorous work performance measurement scheme is the civil service. Recognizing the importance of formal performance management in the civil service, the former Military President, Ibrahim Babangida promulgated Decree 43 in 1988 compelling all civil service establishments to measure and manage performance. Bearing in mind the strategic position of the civil service in the development of a nation, I believe he got this particular act right. This nation may never develop until the public service that employs 80% of all corporate workers in Nigeria adopts an effective scientific approach to eradicate negative and neutral work activities. Unfortunately, special civil service tailored work performance management principles are sparse worldwide. To enable the salient issues in Decree 43 to be addressed scientifically, Charles-Owaba (1994) identified twenty-one human work achievement indicators and showed how to quantify each. Combining with a seven-grade performance scale, Charles-Owaba (2001e) developed a 21 X 7 achievement-grade appraisal instrument applicable for most work situations (see table 7).

Table 7: MANUAL PERFORMANCE APPRAISAL FORM

INDIVIDUAL'S NAME__________ DEPARTMENT /SECTION __________
POSITION __________ APPRAISAL PERIOD__________
QUALIFICATIONS__________ DATE OF APPRAISAL __________
APPRAISER __________

S/O	Achievement Indicators	Possible Range Of Scores For							Performance	
		Very Poor	Poor	Fair	Good	Very Good	Excellent	Very O/Sdg	Grade	Numerical Score
1	Hard work (Output)	0-20	21-40	41-50	51-65	66-80	81-90	91-100		
2	Quality work	0-20	21-40	41-50	51-65	66-80	81-90	91-100		
3	Initiative	0-10	11-20	21-30	31-44	45-50	51-55	56-60		
4	Creativity	0-10	11-20	21-30	31-44	45-50	51-55	56-60		
5	Expertise	0-4	5-8	9-14	15-21	22-24	25-27	28-30		
6	Supervision	0-6	7-12	13-21	22-28	29-32	33-36	37-40		
7	Reporting	0-4	5-8	9-14	15-21	22-24	25-27	28-30		
8	Work Planning	0-4	5-8	9-14	15-21	22-24	25-27	28-30		
9	Leadership	0-20	21-40	41-50	51-65	66-80	81-90	91-100		
10	Dedication	0-10	11-24	25-34	35-55	56-60	61-65	66-70		
11	Honesty	0-10	11-20	21-30	31-44	45-50	51-55	56-60		
12	Self Discipline	0-6	7-12	13-21	22-28	29-32	33-36	37-40		
13	Responsibility	0-6	7-12	13-21	22-28	29-32	33-36	37-40		
14	Reliability	0-6	7-12	12-21	22-28	29-32	33-36	37-40		
15	Punctuality	0-4	5-8	9-24	15-21	22-24	25-27	28-30		
16	Regularity	0-4	5-8	9-14	15-21	22-24	25-27	28-30		
17	Team Work	0-10	11-20	21-35	36-50	51-60	61-70	71-80		
18	Community Contribution	0-3	4-6	7-10	11-14	15-16	17-18	19-20		
19	Hospitality	0-3	4-6	7-10	11-14	15-16	17-18	19-20		
20	Special Contribution	0-3	4-6	7-10	11-14	15-16	1`7-18	19-20		
21	Use of Resources	0-40	41-90	91-140	141-250	215-300	301-350	351-400		
22									OVERALL SCORE =	

Further introducing mathematical appraisal functions, interactive software that computes and displays periodic performance of the staff of an entire establishment was developed and tested (see sample results in table 8). Also identified are forty-three easy to implement civil service motivators (extra reward for above very good achievements). These range from best workers identity display, achievement certificates, finance, promotion and monumental gifts. By neatly tying assorted levels of motivators to corresponding grades of performance in properly clustered government work achievement parameters, a reward system which spurs civil servants to continuously pursue only excellence in positive work was suggested and tested.

Table 8: First Quarter Performance Report of David Adebayo

S/No	Achievement indicator	Grade
1	Hardwork	Excellent
2	Quality of work	Poor
3	Initiative	Excellent
4	Expertise	Very good
5	Supervision	Good
6	Reporting	Excellent
7	Work planning	Excellent
8	Leadership	Very good
9	Dedication	Excellent
10	Honesty	Very outstanding
11	Self-discipline	Very outstanding
12	Responsibility	Excellent
13	Reliability	Excellent
14	Punctuality	Poor
15	Regularity	Very good
16	Teamwork	Excellent
17	Contribution to community	Very outstanding
18	Customer satisfaction	Poor
19	Special contribution to estab	Very poor
20	Use of resources	Poor
22	Overall performance	Good

With a well designed work system, this performance management instrument allows a serious-minded leader to create an enabling work environment for both governors and governed to be continually happy as excellent work is bound to produce excellent policies, services and utilities.

Summary and Concluding Remarks

It is hoped that the existence of the pure and applied science of human work has been amply demonstrated today. The former generates scientific information by critically examining the relationship between the human and his work environment. The latter applies the results to model man-machine work systems; first, to eliminate negative and neutral work activities; and, secondly, to select optimal inputs which will spur workers to concentrate; then creatively improve the grade of positive work activities. The main goals are to enhance safety; eliminate waste; and minimize cost while maximizing quality and quantity of goods, structures and services, the milestones of change.

We have heard of how, by diligent and intelligent work, the 14^{th} to the 16^{th} century great inventions came from Western Europe, particularly Great Britain and France. They conquered and ruled the world empires then. The baton later passed to the United States where the applied science of work gathered maximum momentum beginning from the 17^{th} century. She has been number one in monumental inventions and national development. Soon after World War II, the Japanese increased the ratio of brain to muscle power at the work place and shot herself atop economically. It is on record that Japan has the greatest density of practising industrial engineers worldwide. While recognizing the power of this applied science of work rather late, China went to the extreme of appointing only Applied Work Scientists to head all important government organs. She has won the enviable position of having the third largest world economy. At present, India, Korea, Singapore and Brazil are in the relay race with scientific work as the conveyor for change. It will not be surprising when one of these emerges a world economic power sooner than later. It is a clear path for leaders who care to bring pleasant changes to their citizens. Hence, let my beloved countrymen hear this: only our strong collective will in diligent, intelligent and selfless work can change our fortunes.

Finally, if it is acceptable that the man-machine work system has been the only scientific instrument for monumental positive change, it seems safe to conclude that the **great inventors; the pioneers who initiated and developed the pure and applied science of work; the national leaders who supported its application as well as the work-facilitating inventions are the men, women and machines that change the world.**

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BIODATA OF PROFESSOR OLIVER EKEPRE CHARLES–OWABA

Oliver Ekepre Charles-Owaba was born in Otabi, Ogbia LGA, Bayelsa State in November, 1946. He obtained the First Primary School Leaving Certificate in 1959 at St. Michael School, Oloibiri; and the West African School Certificate (in Division One) in 1966 at Baptist High School, Port Harcourt. Thereafter, he proceeded to the National Technical Teachers College, now Federal College of Education (Technical), Yaba where he obtained the Nigerian Certificate of Education (Technical) in 1971. He worked as a Technical Officer in the Rivers State Public Service, Port-Harcourt, from 1971 to 1973.

He proceeded to Texas Tech University, Lubbock, Texas, United States of America in 1973 to study Industrial Engineering on Federal Government Overseas Scholarship, and obtained his BSc Industrial Engineering degree in 1975. Due to excellent performance (Dean's Honors student), he was admitted into the prestigious *Alpha Pi Mu*, the Industrial Engineering Honor Society of the United States. Consequently, he was appointed Graduate Assistant for both research and teaching of Manufacturing Systems Design at Texas Tech University, USA, where he obtained his MSc and PhD in 1978 and 1981, respectively. .

Dr. Charles-Owaba was an Engineering Consultant to a number of Lubbock County, Texas manufacturing firms, in productivity systems modelling from 1978 to 1980. He worked as an Industrial Engineering Manager at Electric Hose and Rubber Company, Olney, Texas between 1980 and 1981. He returned to Nigeria to serve in the National Youth Service Corps with Shell Petroleum Development Company of Nigeria, Lagos where he developed computer-based petroleum economic models, 1981 to 1982.

He was appointed Lecturer I in the Department of Industrial and Production Engineering, University of Ibadan at the inception of the department's BSc, MSc and PhD Industrial Engineering Programmes in September, 1982 and rose to become a Professor of Industrial and Systems Engineering in 2006.

A versatile and erudite scholar, Professor Charles-Owaba is at home with mathematical modelling and simulation of manufacturing and service systems, with man-machine systems design for quality, safety, and human work process optimization as his specialization. In the manufacturing sector, he developed the first mathematical model and algorithm which provided the theoretical basis for the design of the much celebrated Group Technology (GT) approach to discrete parts manufacture and assembly. He proposed a set sequencing theory which provided a construct for necessary and sufficient optimality conditions to the NP-Hard machine set-up/travelling salesman problem. He applied this theory to develop an algorithm that efficiently solved the machine set-up as well the sequence-dependent machining parameter selection problems. He was the first to quantitatively identify organizational design variables, design parameters and design principles as well as define and solve the business organizational design problem. Professor Charles-Owaba was also the first to apply systems dynamic methodology to develop a safety programme performance measure in terms of environmental risk, accident prevention activities and the associated cost. He developed a general human work performance measurement and motivation model applicable to all categories of personnel in most work situations. He has over sixty publications to his credit including five university-level textbooks. His expertise in developing and teaching special-need topics to corporate staff has been well known to most public service and production establishments in the federation. For example, he is a well recognized facilitator in the Special Intensive Training Programme (SITP), Shell; and FSTP-E-II of NNPC.

The volume of Professor Charles-Owaba's scholarly activities is matched only by his professional and administrative activities. He is a COREN registered Engineer; Fellow, Nigerian Institution of Engineering Management; Member, Nigerian Institute of Industrial Engineers and Member, Nigerian Society of Engineers. He once served as the Director, Departmental Post-Experience Short Course Programme; Chairman, Faculty of Technology Consultancy Services, University of Ibadan, and Chairman, National Productivity Guideline Drafting Committee; Sub-Dean (General), Faculty of Technology, University of Ibadan, and Technical Adviser, National Productivity Centre, Abuja.

As a university don, Professor Oliver Ekepre Charles-Owaba is a much respected teacher, research students' supervisor and mentor. One of his major contributions in the University of Ibadan is the initial development and periodic review of the MSc and PhD Industrial Engineering programmes which, in terms of academic standards, effectively compare with others' internationally. He successfully embarked on teaching capacity building as most of the lecturers were, at one time or the other, his students. He has successfully supervised seven PhD candidates (four in progress) and over sixty MSc research students in the University of Ibadan. He was twice voted the best teacher by the students of his department. He has held a number of administrative positions and served on various committees at the University of Ibadan and other Nigerian Universities. For example, he has been Acting Head of the Department of Industrial and Production Engineering from 1988-1991; 1994-2006 and Head of Department, 2008-2009. He has in addition served as external examiner to a number of Nigerian Universities; the chief editor of the Journal of the Nigerian Institute of Industrial Engineers; and member of the editorial board of several engineering journals. He has been a member of the Boards of Directors of a few corporate firms. He was a Visiting Professor to the School of Engineering, Southern Illinois University, Edwardsville, USA from 2006 to 2007.

Professor Charles-Owaba is a devoted Christian, happily married with children and grand children.