**OPERATION, MAINTRNANCE AND MANAGEMENT OF ENGINEERING EQUIPMENT**

**FOR SUSTAINABLE DEVELOPMENT IN NIGERIA**

**BY**

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**ABSTRACT**

Today’s construction projects are highly mechanized and becoming more so every day. With the growing industrialization of construction work, the role of onsite equipment and machineries is vital in achieving productivity and efficiency. During the construction phase, selection of right equipment has always been a key factor in the success of any construction project. This decision is typically made by matching equipment available in a fleet with the tasks at hand. Such analysis accounts for equipment productivity, equipment capacity, and cost. However, the emerging notion of sustainability in construction has emphasized energy conservation, efficiency, green environment, economy and human well being. In this context, selecting the most appropriate equipment from the available options is highly challenging. Therefore, this paper aims to determine a selection criteria based on the fundamental concept of sustainability and provides an assessment framework. A questionnaire survey was conducted among a classified group of Malaysian contractors to elicit information pertaining to the sustainable selection of onsite machineries. The findings of this study will guide the decision makers to appraise the selection process of construction equipment on the triple bottom line of sustainability.

Keywords

Construction equipment selection Sustainable criteria Construction management Mechanized construction Sustainable construction

**SUSTAINABLE DEVELOPMENT MEANING**

What is Sustainable Development?

The term “sustainable development” was first proposed by the World Commission on Environment and

Development (WCED) in its 1987 report Our Common Future (also known as the Brundtland Commission

report). WCED, which included 23 members from 22 countries, was formed by the United Nations in 1984,

and for three years studied the conflicts between growing global environmental problems and the needs of less-developed nations.

WCED’s widely used definition of sustainable development is:

“Meeting the needs of the present without compromising the ability of future generations to meet their own needs.”

Since 1987, there have been many efforts to explain and amplify what is meant by sustainable

development.

To an engineer, a sustainable system is one that is either in equilibrium, or one that changes slowly at a tolerable rate. This concept of sustainability is best illustrated by natural ecosystems, which consist of nearly closed loops that change slowly. For example, in the food cycle of plants and animals, plants grow in the presence of sunlight, moisture and nutrients and are then consumed by insects and herbivores which , in turn, are eaten by successively larger animals. The resulting natural waste products replenish the nutrients,

which allows plants to grow and the cycle to begin again.

If humans are to achieve sustainable development, we will have to adopt patterns that reflect these natural processes.

The roles of engineers in sustainable development can be illustrated by a closed-loop human

ecosystem that mimics natural systems. This model of a closed-loop ecosystem was first proposed in 1990.

**MAINTENANCE ENGINEERING**

Maintenance Engineering is the discipline and profession of applying engineering concepts for the optimization of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment.

Maintenance, and hence maintenance engineering, is increasing in importance due to rising amounts of equipment, systems, machineries and infrastructure. Since the Industrial Revolution, devices, equipment, machinery and structures have grown increasingly complex, requiring a host of personnel, vocations and related systems needed to maintain them.[1] Prior to 2006, the United States spent approximately US$300 billion annually on plant maintenance and operations alone.[1] Maintenance is to ensure a unit is fit for purpose, with maximum availability at minimum costs. A person practicing maintenance engineering is known as a maintenance engineer.

**Maintenance engineer's description**

A maintenance engineer should possess significant knowledge of statistics, probability and logistics, and additionally in the fundamentals of the operation of the equipment and machinery he or she is responsible for. A maintenance engineer should also possess high interpersonal, communication, and management skills, as well as the ability to make decisions quickly.

**Typical responsibilities include**

1.Assure optimization of the Maintenance Organization structure

2.Analysis of repetitive equipment failures

3.Estimation of maintenance costs and evaluation of alternatives

4.Forecasting of spare parts

5.Assessing the needs for equipment replacements and establish replacement programs when due

6.Application of scheduling and project management principles to replacement programs

7.Assessing required maintenance tools and skills required for efficient maintenance of equipment

8.Assessing required skills for maintenance personnel

9.Reviewing personnel transfers to and from maintenance organizations

10.Assessing and reporting safety hazards associated with maintenance of equipment

**Maintenance engineering education**

Institutions across the world have recognized the need for maintenance engineering. Maintenance engineers usually hold a degree in Mechanical Engineering, Industrial Engineering, or other engineering disciplines. In recent years specialized bachelor and master courses have developed. The Bachelor Degree program in Maintenance Engineering at the German-Jordanian University in Amman is addressing the need, as well as the Bachelor Programme in Maintenance Engineering at Luleå University of Technology. With an increased demand for Chartered Engineers, The University of Central Lancashire in United Kingdom has developed a MSc in Maintenance Engineering currently under accreditation with the Institution of Engineering and Technology and a Top-up Bachelor of Engineering with honors degree for technicians holding a Higher National Diploma and seeking a progression in their professional

1. **Introduction**

All construction projects require different types of equipment and machineries having their own level of application. For example residential projects have a low level of equipment usage. It requires simple and traditional machines like fork-lifters, backhoes, hauling and hoisting equipment, material handling along with pneumatic tools. Commercial projects have moderate usage of equipment and machineries. Industrial and heavy construction projects required intense and high utilization of machinery for carrying out mass excavation, stabilizing, compacting, asphalt paving and finishing, pipelines, railroads and many other special activities (Gransberg et al., 2006). The common application of heavy construction equipment includes but is not limited to; earthwork, structural steel works, concreting, building, lifting and positioning of components (Mahbub, 2012). Heavy construction activities are further grouped into horizontal and vertical construction. The former type of construction required more ground work whereas the later one is characterized by more lifting works rather than excavation and earth works (Gransberg et al., 2006). The roles of heavy equipment are very vital for increasing the construction productivity especially for infrastructure works. However, their acquisition is very much capital intensive for construction firms. It is also considered as a major financial burden during the construction phase beside other expenditures (Prasertrungruang and Hadikusumo, 2007). The past research shows that the acquisition of heavy equipment constitutes 36 percent of the total project cost and possesses high risk and uncertainties for the owners (Yeo and Ning, 2006).

This increased level of awareness and the application of mechanized equipment and machineries are considered as a positive thrust for the advancement of construction industry. It has abundance of benefits for all the stakeholders. Nevertheless, its adoption has significant drawbacks for the environment and the people working in its vicinity. The emerging concept of sustainable or green construction emphasizes the minimization and elimination of harmful impacts to the environment (Nunnally, 2000). Construction organizations are accountable for the impacts of an implemented project on the society, environment and economy long after the project has been completed. Therefore, construction and sustainable development issues are closely related because this sector is a principal contributor to global resource depletion (Rees, 1999). According to International Council for Building (1999), the buildings in European Union countries are accountable for more than 40% of the total energy consumption and construction sector is estimated to generate approximately 40% of all man-made waste. Sustainable development has now become a significant subject discussed and debated at various levels e.g. national, international, governmental, non-governmental and as well within the academic circles as an agenda of socio-economic and environmental development. A fair amount of diversity exists among the definitions of sustainability and sustainable development. However, most of them agree that the concept is based on three pillars i.e. social, environmental and economic considerations (Labuschagne and Brent, 2005). The most common and well-known definition for sustainable development is defined by the World Commission on Environment and Development (1987) which is stated as “satisfaction of present needs without compromising the ability of future generations to meet their own needs”. Sustainability is, therefore, considered as an ultimate objective where balance in socio-economic activities and environmental concerns is appropriately addressed. The concept of sustainability in construction has been reviewed by many researchers and its focus keeps on shifting with passage of time (Boonstra et al., 1998, Cole and Larsson, 1998, Hakkinen et al., 2002, Brophy and Lewis, 2005, Kibert and Hoboken, 2005). As such, the sustainable construction is a broad term and it includes processes from preliminary to detailed design, engineering, planning and procurement consideration toward the approved deliverables of the client, and then the different stages over the product’s lifetime which consist of operation, maintenance, refurbishment, re-construction, demolition and recycling (Persson et al., 2008). International Council for Building (1999) in the Agenda 21 emphasized on the notion of sustainable construction through environmental, socio-economic and cultural aspects. This agenda has identified many vital issues and challenges such as, management and organization; product and building issues and resource consumption in construction. The past studies have shown that environmental focus in construction was more towards the material selection, structure design, materials recycling rather than greenhouse gas emissions (Kim et al., 2012). Furthermore, previous efforts to reach sustainability have primarily focused on the environmental performance of facilities in the “use” phase, and such efforts are lately being expanded to mitigate environmental impacts from the “construction” phase (Peña-Mora et al., 2009). Among the environmental impacts from construction processes (such as waste generation, energy consumption, resource depletion, etc.), emissions from onsite construction equipments account for the largest share (more than 50%) of the total impacts (Guggemos and Horvath, 2006). All non-road construction equipment, machineries and vehicles which are power-driven by diesel engine have a high impact on environment. The emissions from these equipments are considered as a source of air pollution. The United States Environmental Protection Agency (EPA) stated that the US construction industry is comprised of approximately two million equipment, machineries and vehicles which are powered by diesel engines. These engines are operated by fossil fuels, hence discharge significant amount of carbon dioxide, hydrocarbons and particulate matter. EPA report further exemplifies that a road bulldozer with an engine capacity of 175 hp releases particulate matter which is equal to the emissions produced by 500 new auto mobiles (Lewis et al., 2009). In the United States, 5839.3 million metric tons (MTs) of CO2 is produced by the usage of fossil fuels to operate heavy construction equipment in 2008 (USEIA, 2009). According to the Korean Institute of Construction Technology (2010), air pollutant emissions from onsite construction equipment account for 6.8% (253, 058 MTs/year) of the overall emissions produced in Korea in 2009. The average rate of production of emissions is much greater for construction equipment as compared to passenger vehicles because of differences in the type of fuel i.e. diesel versus gasoline, engine technology and horse power (NESCAUM, 1997). As an example, earthwork produces highest percentage of GHG emissions among all construction activities (Kim et al., 2012). Equipment categorization, age and horsepower and as well as type of fuel used, can greatly affect rates of emissions (Avetisyan et al., 2012).

Therefore, during the selection of construction equipment, there is a need for the most rational criteria that have a positive impact on operational efficiency, productivity, cost minimization and as well as environmental and human well being. These criteria make it possible for the contractors to consider the sustainability agenda in the equipment selection procedures. Hence, this study aims to determine the factors that influence the sustainable selection of onsite construction equipment and machineries.

**2. Review of criteria for the selection of construction equipment**

The primary agenda of equipment selection process is to achieve higher productivity, more operational flexibility and viable economic considerations. The past research shows that the appropriate selection of equipment has always been considered as a strategic decision during the construction phase of any project (Tatari and Skibniewski, 2006). With the growing industrialization and mechanization, this is getting even more important and complex for companies to assess and make the best decision from the pool of many alternatives (Schaufelberger, 1999). It is due to this reason that this issue has grasped the attention of many researchers and as well as a number of academic studies have been carried out to improve the mechanized construction practices (Shapira and Goldenberg, 2005). Selection of equipment is typically made by matching equipment in a fleet with tasks. Such matching accounts for equipment productivity, equipment capacity, and cost (Gransberg et al., 2006). It usually involves the selection of the best option among many alternatives based on criteria and method that can be used for the decision making process. Gates and Scarpa (1980) stated that when a contractor selects earth moving equipment, he should look into these four categories: (1) spatial relationships, (2) soil characteristics, (3) contract provision and (4) logistical considerations. According to them, spatial relationships were further classified into seven factors mainly belonging to geographic information of the construction site. Whereas, soil characteristics cover the ability of soil to support earthmoving operations. Gates and Scarpa (1980) put quantities of excavation, moving and fill; construction duration; mode of payment; legal limitations; weight and size of equipment; working constraints such as hours, dust, noise and traffic in contract provisions. Logistical considerations were also included which primarily cover cost, availability of equipment and experience of operator. Another research undertaken by Chan and Harris (1989) has established a data base application for the equipment selection. In their spread sheet, they have used technical criteria for the selection of best backhoes and loaders during earth moving operations. Chan et al. (2001) have developed evaluation criteria for the selection of material handling equipment. Their research work identified performance measure, technical, economic and strategic aspects as the evaluation criteria. Haidar et al. (1999) split the equipment selection process into knowledge based and optimization genetic algorithms. The former part involves procedures that screen the desired equipment from the list based on subject knowledge whereas the later one refines the selection on the basis of criteria. These criteria include production rate, ownership cost, operating cost, equipment characteristics along with manufacturer, model, number and operating life. Bascetin (2003) has established a decision support system by using qualitative and quantitative factors for the selection of open pit mining equipment. He classified the selection criteria into cost and operational technical requirements. In a study that was undertaken by Shapira and Goldenberg (2005), a list of tangible (hard) and intangible (soft) factors were identified. The tangible factors include technical specifications, site conditions and cost consideration. The intangible factors are qualitative and include safety considerations, company policies regarding equipment acquisition, market conditions and environmental constraints. It is an important aspect that this research work raises the issue of soft consideration in the selection of construction equipment in building projects. Chamzini and Yakhchali (2012) have identified the nine point criteria and classified them into two broad categories i.e. benefit criteria based on technical performance and cost criteria.

**3. Development of sustainable criteria**

The selection of criteria for an assessment framework mainly depends on a number of factors. It may include accessibility of information and intricacy of analysis (Azapagic and Perdan, 2000). In terms of sustainability, it must address an integral approach that encompasses suitable measures that reflect economic, environment and social aspects (Singh et al., 2009). Prescott (1995) established a mechanism for integrating environmental and social elements of sustainable development. In this mechanism, he has emphasized that inclusion of ecosystem and human well-being is evenly required for achieving sustainable development. Guy and Kibert (1998) established that criteria should provide a systematic approach in order to measure the sustainability of a system in a simple and easy manner. These indicators are also helpful to measure the progress of sustainable activities for the whole system. They further argued that the elements of sustainable criteria in construction will focus on land issues beside water, energy and material use. In their opinion, quantitative measurement of these indicators provides a framework to assess sustainability in construction. Wackernagel and Rees (1996) developed an ecological criterion that is related to economic and environmental aspects of sustainability. It includes food, water, energy and waste disposal on per capita basis. Bourdeau (1999) identified economic, social and cultural criteria as the essential elements of his sustainability framework for the construction industry. He further established that the priorities of sustainable criteria have geographical diversity and it may vary around the globe. Foxon et al., (2002) established sustainability criteria for a decision support system for water utilities in the UK construction industry. His research work identified two main factors that support the development of sustainable criteria. According to him, application of the set of criteria and its practicability under the agenda of sustainability are main concerns. Singh et al. (2009) stated that sustainability indices are gaining considerable importance and effective tool for formulation strategy. It is valuable in making policy in terms of environment, socio-economic and technological improvements. Their research work further emphasized that indicator of sustainable development should be carefully selected, refined and revisited in order to maintain its contextual effectiveness. Labuschagnea et al. (2005) mentioned that United Nations Commission on Sustainable Development (CSD) has defined four main categories for assessing the government efforts to achieve sustainable development. The CSD sustainability model comprises of social, environment, economic and institutional elements and it is further spilt into main and sub-indicators. The Institution of Chemical Engineers (IChemE) has also devised sustainability metrics which include three fundamental criteria i.e. environment, economic and social. It may be further broke down into nine sub-indicators. This sustainability model is specifically meant for measuring sustainability of process industries. Another framework proposed by Wuppertal Institute comprised of four dimensions of sustainable development which include environment, economic, social and institutional indicators. In this framework, all four major criteria as proposed by CSD are linked with each other through various sub-indicators. Jeon and Amekudzi (2005) have addressed sustainability in public transportation system by defining indicators and metrics. Their research work indicated that consensus should be developed on economy, environment and social well-being of society while addressing the sustainable trends in transportation.

**4. Research methodology**

This research was conducted by using both the qualitative and quantitative research methods. The qualitative research approach is required to develop a basis to establish background knowledge about selection of onsite construction equipment. In this phase of research, relevant published data from periodicals, journals, conference proceedings, web-based knowledge and other research reports were analyzed. The thorough literature survey on the secondary data helps to develop a framework for the intended research. This secondary data were further analyzed to develop research instrument such as structured interview and questionnaire survey. Structured interviews and pilot survey were conducted from the selected construction practitioners to fill any gap and shortcomings before the full scale questionnaire survey. During this phase, all reported relevant factors for the selection of onsite construction equipment were listed, scrutinized and verified from the participants. A total number of 25 industry professionals were contacted for face to face structured interview and subsequent pilot study questionnaire survey. Their understandings and views were solicited during the individual interview session. The results of the pilot survey provide an overall satisfactory picture of the questionnaire items, scales, and measures. The main constructs of the study were assessed for reliability using Cronbach’s alpha coefficient. Ideally, the Cronbach alpha coefficient of a scale should be greater than 0.70 (Iarossi, 2006). The reliability analysis revealed that most of the scale items have higher reliability values (i.e. Cronbach’s Alpha = 0.981). This is consistent with their use in the precedent studies. Majority of the participants found the questionnaire understandable and easy to respond. Moreover, the questionnaire can be easily completed within 20–25 minutes of time. However, minor changes are required in some of the questions, such as, wording of questions which needs to be revisited; and some items of question which should be positively worded and positioned. No confrontational feedbacks were received from the interviewees and participants of the pilot study questionnaire. So, it was decided to compile the final survey questionnaire for the next phase of investigation. From the outcome of pilot study, a total of 38 criteria or indicators were established and these formed the basis of the descriptive survey. The primary data required for this study were collected through descriptive questionnaire survey. This methodology is considered as cost effective and time saving in order to achieve better results in shorter duration. The traditional techniques for collecting responses from the targeted respondents are postal mails, fax and electronic mails. However, for this research work a web survey tool was used effectively for getting feedbacks from the respondents. This has helped us a lot in achieving momentum and a good data base of the survey participants. For the purpose of achieving the desired research objectives, a structured or close-ended questionnaire was designed to gain the views from the industry practitioners. A Total number of 400, Grade G7 contractors were randomly selected from Construction Industry Development Board (CIDB) Malaysia database.

This sample size is selected from the list of around 2500 Kuala Lumpur and Selangor based contractors. In Malaysia, Grade G7 Kuala Lumpur and Selangor based contractors are large contractors and usually engaged in heavy and complex construction activities with no financial limit. Hence, they are more familiar with the phenomenon of sustainable practices for onsite construction activities. Before sending the questionnaire, it was duly confirmed and assured that all the targeted respondents are doing construction business and engage in civil and infrastructure works. The Master Builder Association of Malaysia survey indicates that despite a high percentage of contractors in the country, only 12% are actually running construction business (Bahaman, 2011). The first section of survey questionnaire comprised of respondents demographic information and their organizational background. The second section is based on a Likert scale question which asked the respondents to rate the importance of criteria on a five point scale. After a rigorous follow-up, 126 responses were received. After removing invalid and incomplete responses, a total of 86 completed questionnaires were acknowledged and taken into consideration. This gives an overall response rate of 21.5%. This response rate is well acceptable in the view of researchers. According to them, the outcome of a postal survey for the construction industry is usually in the range of 20–30 percent (Akintoye, 2000, Dulami et al., 2003). Hence, the current percentages of feedbacks are good enough for a meaningful analysis.

**5. Results and analysis**

**5.1. Background and general information**

The importance of demographic information cannot be undermined for a meaningful quantitative analysis. During the empirical survey, background and general information from the respondents were also sought. As the aim of research is focused on the construction phase of the project, so it was envisaged to get on board all the key players of construction project team having satisfactory professional experience. Table 3 shows the summary of respondent’s demographic information. Analysis of the feedbacks shows that respondents are mainly from the private sector and having satisfactory working experience. Among them, 36.2% of the respondents have working experience within the range of 11 to 20 years, while 43.54% have more than 20 years of field experience. The result of the survey shows that 88% of the respondents have completed their bachelor’s education. Some of the respondents have also acquired additional postgraduate qualifications i.e. MSc and Master degree with a percentage of 3.25% and 4.8% respectively. Demographic data also show the involvement of construction firms in different infrastructure projects. This mainly includes roads, highways, bridges and pipelines construction projects. The respondent’s demographic information reveals that they have good academic background and satisfactory knowledge for providing sufficient details and inputs for the outcome of this research work. The statistics represent that the questionnaires are mostly filled by the experienced and senior professionals having vast experience in construction projects. Their opinions and views are quite important and valueable in order to establish the findings.

**5.2**. **Ranking analysis for criteria**

The respondent’s feedbacks on the ranking criteria were rated on a five point Likert scale (1–5). The scale provides an ordinal type as rank orders are in the form of; extremely important, very important, neutral, low important and not at all important. In order to ensure the reliability of the scale, Cronbach’s alpha coefficient value of each of the construct was measured. Cronbach’s alpha determines the internal consistency of each of the three main criteria i.e. socio-economic, engineering and environmental and their alpha values are 0.923, 0.967 and 0.969 respectively. As these values are greater than 0.7, hence the internal consistency is satisfactory and acceptable for appraising the criteria. For the research undertaken, it is to be observed that responses were received on a (1 – 5) Likert scale. Therefore, use of parametric methods is not practicable and applicable for assessing preferences of the respondents (Siegel and Castellan, 1988). So, relative importance index method was used for determining the relative importance of sustainable criteria. Relative Importance Index (RII) is a non-parametric technique widely used by construction and facilities management researchers for analyzing structured questionnaire responses for data involving ordinal measurement of attitudes (Kometa et al., 1994). For this part of the questionnaire, the five-point likert scale of 1 to 5 (with 1 = not at all important, 2 = low important, 3 = neutral, 4 = very important and 5 = extremely important) was adopted and the relative importance indices (RII) for each of the sustainable criteria. Eq. 1 shows a formula which was used to find out the relative index (Olomolaiye et al., 1987, Chan and Kumaraswamy, 1997).

**5 Meaning of underlying factor analysis**

**5. 3Life cycle cost**

There are three basic methods which are adopted by civil contractor to procure equipment and machineries. Buying includes 100% ownership, whereas rental and leasing agreements are at a fixed monthly fee for a pre-defined period (Gransberg et al., 2006). The selection of these methods largely depends upon the contractors’ financial decisions. Normally many large contractors are willing to own equipment as compared to smaller construction companies who cannot afford to own every piece of equipment. The life cycle cost (LCC) assessment factors include the cost of elements which are important for calculating the construction equipment costs. During the execution phase, construction equipment and machineries worth is approximately 30 percent of the total company assets (Vorester, 2005). This shows a large investment in terms of financial burden to the procuring organization. Hence, the life cycle cost analysis is a main concern of contractors with the aim to determine the owning and operating cost for the items to be procured. LCC factor includes ownership cost and operational cost. The ownership cost is the expenses which are incurred by the contractor to own the equipment. It may include; initial capital cost; depreciation; interest; insurance cost; taxes and storage cost. On the other hand, the operating cost includes fuel expenses; service and repair cost; cost of consumables and special items along with operator charges. The emerging concept of sustainability in construction industry is mounting pressure on the organizations to provide environment friendly solutions with an emphasis on achieving financial optimization. However, with the only consideration of initial capital cost, this could be not attained. With the use of LCC analysis, the decision makers will be in a far better position to have a thorough evaluation among the available options and identify the most sustainable alternative for the construction project.

**5.4Performance**

Performance measuring indicators are used to control and improve the utilization of the equipment. The conformance of performance measures by the equipment fleet is proportional to its economic viability. Higher the operational performance of the equipment, the more will be its profitability (Alwood, 1989). In terms of sustainability, the concept of performance provides a robust and a fundamental basis for evaluating a rational procurement. One aspect of the construction equipment procurement is to select an optimum equipment fleet. This factor has seven items which include equipment efficiency, capacity, productivity, reliability, operating life of equipment and its age. These seven items are important in a way that they are essential for effective equipment management practices.

**5.5 System capability**

The variable loading for the third factor is focused on “System capability”. It is considered as a spine of an equipment design. It is a barometer for measuring performance, operation and production capability of a typical earthmoving equipment (Tatum et al., 2006). The better understanding and inclusion of this factor in the selection criteria significantly implies its relevance for smart acquisition practices. This factor uses six items that make up a construction equipment. These items are; structure and suspension system, power train system, traction system, implement system, control and information system and machine standardization. The first five items form a typical earthmoving equipment whereas the last item i.e. machine standardization represents the utilization of equipment with the identical components and auxiliaries having similar specifications and characteristics. This practice has certain benefits in terms of lower repair and maintenance cost, high operational efficiency (Tavakoli et al., 1989).

**6 Operational convenience**

The fourth factor is related to “Operational convenience”. It includes six items such as easy repair and maintenance, meet job and operational requirements, spare parts availability, compliance with site operating conditions, versatility of equipment and meet haul road conditions. All these items are considered to be vital for making a decision.

**7 Environmental impacts**

The fifth factor is concerned with the environmental health issues pertaining to the usage of construction equipment. The construction equipment has substantial impact on the environment. All non-road construction equipment, machineries and vehicles which are power-driven by diesel engine have a high impact on environment. The emissions from these equipments are considered as source of air pollution (Guggemos and Horvath, 2006). Therefore, sustainable planning of mechanized operations should comply environmental regulations and it is equally important to address this issue in the selection and use of construction equipment. The growing need of environmental concerns and legislations has led to adoption of emissions reduction techniques and safe operation of construction equipment and vehicles (Lewis et al., 2009). The Environmental impact factor includes items such as oil and lube leakage control, use of biodegradable lubricants and hydraulic oil, quantity of particulate matter, fossil fuel consumption, use of sustainable fuels, greenhouse gas emissions, energy saving, noise control, vibration control and environmental statuary compliance. In making a sustainable decision, these items are essential guide in order to complement the environmental objectives.

**8 Social benefits**

The sixth factor is associated with “Social benefits”. It is composed of seven items such as operator view and comfort, operator proficiency, training needs, operator health, availability of local skilled operator, relationship with supplier and safety features. The availability, proficiency and subsequent employment of local skilled operator are positive approaches in terms of creating a job market. It has a high impact on lowering the unemployment rate in a developing country. Past studies have also established that construction equipment, plant and machineries are major causes of site accidents and injuries (Idoro, 2011). The operation of mechanized equipment has a direct impact on worker’s health. This is due to the fact that health and safety considerations for operators are kept at the lowest priorities in executing construction activities (Mbuya and Lema, 1996). Therefore, it is pertinent to consider items that are concerned with the occupational safety and health procedures of workers. This factor has also included an item which is relevant to the equipment suppliers. A good and accommodating liaison with the concerned dealer or supplier is beneficial in reducing the overall procurement procedures.

**Conclusion**

This study has presented an over view of earlier research and investigations in terms of significant measures for the selection of construction equipment. Based on the qualitative and quantitative findings, the study has established criteria for the selection of sustainable construction equipment for onsite mechanization. The sustainable criteria presented as a result of this endeavor are different from the conventional way of procurement which emphasizes on cost, time and quality. However, in view of the global shift toward sustainability, it is imperative to incorporate it in every aspect of construction process. The proposed criteria are envisaged to assist civil contractors in the selection and deployment of construction equipment and machineries that meets the triple bottom line of sustainability i.e. profit, planet and people. A total of six factors were derived from the Varimax rotation method of factor analysis. The principal factors are life cycle cost, performance, system capability, operational convenience, environmental impact and social benefits. These factors are correspondingly loaded with thirty eight items which form criteria based on the socio-economic, engineering and environmental functions of sustainability. The factors and its associated items have formed a fundamental basis for the sustainable equipment selection process. It is important to note that all item values are significant and have high loading values. The statistical analysis reveals that all criteria items were ranked as “High” or “High-Medium” categories. Among them, the top five criteria’s consisted of equipment productivity, safety features, ownership cost, operational cost and its efficiency. None of the environmental criteria is among the top five ranking. This shows that environmental considerations are still at low priority for the selection criteria. Since these items were extracted and ranked from the feedbacks of industry experts, so it shows their relative importance level to meet the sustainable criteria for the selection and evaluation of construction equipment.

It is intended to have in-depth case studies to verify the applicability and usefulness of the identified sustainable criteria. This will lead the industry professional toward a rational decision making in promoting an overall green construction paradigm for our globe