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Criteria for the selection of sustainable onsite construction equipment

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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

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 exca-

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vation 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, reconstruction, 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 CO_2 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. Table 1 shows the summary of different criteria that affect the equipment selection in construction projects.

The above findings elaborate that researchers are more focused on the cost and technical aspects of equipment selection. This shows that environmental and social concerns in the equipment selection are ignored. It has also been revealed from a survey that health, safety and environmental issues are being kept at average and low priority during equipment selection in Malaysian construction industry (Waris et al., 2013). In contrast to this, the agenda of sustainable or green construction emphasis that the appraisal of equipment selection must be in accordance with the technical, socio-economic and environmental functions. The next section will describe the detailed approach for the development of sustainable criteria for the selection of onsite construction equipment.

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

Table 1
Summary of precedent research defining the equipment selection aspects.

Gates and Scarpa (1980)	Chan and Harris (1989)	Chan et al. (2001)	Haidar et al. (1999)	Bascetin (2003)	Goldenberg and Shapira (2007)	Chamzini and Yakhchali (2012)
• Technical criteria • Cost criteria • Contractual obligations • Logistics	• Technical criteria	• Performance measure • Technical aspects • Economic aspects • Strategic aspects	• Production rate • Ownership cost • Operating cost • Equipment characteristic	• Cost criteria • Operational requirement • Technical requirement	• Cost estimates • Technical specification • Site conditions • Safety • Company policy • Market condition • Environmental constraints	• Cost criteria • Technical performance criteria

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

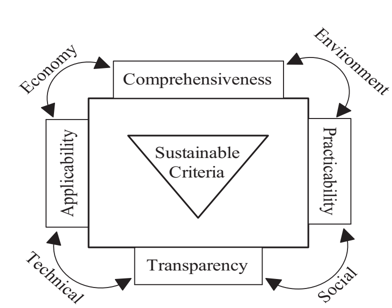

Figure 1. Sustainable criteria development flow diagram (Akadiri and Olomolaiye, 2012).

society while addressing the sustainable trends in transportation. Akadiri and Olomolaiye (2012) have proposed holistic guidelines for the development of criteria (Fig. 1).

These guidelines were based on the research work of Singh et al., 2007; Chen et al., 2010. According to them, sustainability criteria should be comprehensive and it must cover four basic categories, i.e. economic, environmental, social and technical aspects of sustainable construction. In addition to this, the selected criteria should be applicable to a broad range of options with transparency and practicability for a meaningful analysis.

The above literature review shows that researchers have same opinion on the fundamental aspects of sustainability. Precedent research has emphasized on economic, environment, social and technical measures of sustainable performance. These performance measures are guiding principles for making the selection criteria. In order to develop a broad based, effective and meaningful criteria which encapsulate the fundamental aspects of sustainability in the selection of onsite construction equipment. A number of prior indicators in this area are combined with the concern of sustainability. As an outcome, these criteria are classified under three categories of sustainable development;

(a) Socio-economic
(b) Engineering
(c) Environment

Table 2 shows the summary of selection criteria based on the derived data from the previous related research.

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 con-

Table 2
List of sustainable criteria for the selection of onsite construction equipment.

	Socio-economic criteria	Engineering criteria	Environmental criteria
Summary of literature review	Ownership cost Peurifoy et al. (2006) Operational cost Gransberg et al. (2006) Availability of local skilled operator Zaki et al. (1996) Operator health Kittusamy and Buchholz, (2004) Operator view and comfort Caterpillar (2011) Safety features Arslan et al. (2004) Operator proficiency Alkass et al. (1993) Training needs for operator Mackenzie et al. (2000) Relationship with dealer/supplier Prasertrungruang and Hadikusumo (2009)	Equipment age Goldenberg and Shapira (2007) Equipment capacity Alkass et al. (1993) Equipment reliability Arslan et al. (2004) Equipment efficiency Prasertrungruang and Hadikusumo (2009) Equipment operating life Valli and Jeyasehar (2012) Equipment productivity Eldin and Mayfield (2005) Fuel efficiency Caterpillar (2011) Implement system Tatum et al. (2006) Traction system Tatum et al. (2006) Structure and suspension system Tatum et al. (2006). Power train system Tatum et al. (2006). Control and information system Tatum et al. (2006). Compliance with site operating conditions Alkass et al. (1993; O'Brien and Zilly (1971) Meet job/operational requirements Haidar et al. (1999) Meet haul road condition Eldin and Mayfield (2005) Versatility of equipment Jrade and Markiz (2012) Easy repair and maintenance Valli and Jeyasehar (2012) Machine/equipment standardization Tavakoli et al. (1989) Spare parts availability Prasertrungruang and Hadikusumo (2009)	Greenhouse gas emissions Yan et al. (2009) Fossil fuel consumption Sharrard et al. (2007) Energy saving Kim et al. (2012) Noise control Koo and Ariaratnam (2008) Vibration control Koo and Ariaratnam (2008) Quantity of particulate matter Hajji (2013) Oil/lube leakage control USEPA (2007) Use of sustainable fuels Lewis et al. (2009) Use of biodegradable lubricants and hydraulic oil Boyde (2002) Environmental statutory compliance USEPA (2007)

struction 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

Table 3
Respondent's contextual information.

S. No.	Variables	Frequency	Percentage (%)
A	*Job title*		
	Project manager	43	34.7
	Construction Manager	09	7.3
	Manager	34	27.4
	Engineer	14	11.3
	Quantity surveyor	23	18.5
	Equipment Manager	01	0.8
B	*Respondent experience*		
	<5 years	5	4.03
	6–10 years	20	16.12
	11–20 years	45	36.2
	>20 years	54	43.54
C	*Level of education*		
	Bachelor	110	88
	Master of Science	4	3.2
	Master of Business Administration	2	1.6
	Master	6	4.8
	PhD	2	1.6
D	*Age of organization*		
	<5 years	06	4.83
	6–10 years	34	27.41
	11–20 years	43	34.67
	>20 years	47	37.9
E	*Size of organization*		
	<100 staff	10	8
	101–250 staff	25	20
	251–500 staff	45	36.2
	>500 staff	44	35.4
F	*Area of specialization*		
	Roads and highway	75	60
	Railway	8	6.5
	Dams and irrigation	19	15.3
	Bridges	32	25.8
	Ports	11	8.9
	Tunneling	9	7.3
	Airports	27	21.8
	Pipelines	42	33.9

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).

$$RII = \frac{\Sigma w}{A \times N} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5 \times N} \tag{1}$$

Where W shows the weighting that is assigned to each variable by the respondent, A is the highest weight and N is the total number of respondents. The RII value ranges from 0 to 1 with 0 not inclusive. It shows that higher the value of RII, more important was the sustainable criteria and vice versa. The comparison of RII with the corresponding importance level is measured from the transformation matrix as proposed by Chen et al. (2010). According to him, derived importance levels from RII are as follows:

High (H)	$0.8 < RII < 1.0$
High-Medium (H-M)	$0.6 < RII < 0.8$
Medium (M)	$0.4 < RII < 0.6$
Medium-Low (M-L)	$0.2 < RII < 0.4$
Low (L)	$0.0 < RII < 0.2$

Table 4 shows the Relative Importance Index (RII) of the sustainable criteria along with the corresponding ranking and their importance level. It is evident from the ranking table that twenty five criteria were identified as "High" importance levels which are considered of prime importance for the selection of sustainable construction equipment. These "High" importance indicators have Relative Index (RII) in the range of 0.875–0.802. These high ranking criteria include socio-economic, engineering and environmental criteria. These 25 indicators are $E_{ng}1$: Equipment productivity, S_E3:Safety, S_E1: Ownership cost, $E_{ng}2$: Spare parts availability, S_E2: Operational cost, $E_{ng}3$: Equipment efficiency, $E_{ng}5$: Equipment reliability, $E_{ng}4$: Easy repair and maintenance, S_E4: Availability of local skilled operator, $E_{ng}6$: Equipment capacity, $E_{ng}7$: Equipment operating life, $E_{ng}8$: Meet job/operational requirements, $E_{ng}9$: Fuel efficiency, E_n1: Energy saving, S_E5: Operator health, E_n2: Quantity of particulate matter, $E_{ng}10$: Compliance with site operating conditions, S_E6: Operator proficiency, E_n3: Greenhouse gas emissions, E_n4: Oil/lube leakage control, S_E7: Training needs for operator, $E_{ng}11$: Equipment age, E_n5: Fossil fuel consumption, $E_{ng}12$: Implement system and E_n6: Noise control.

"Equipment productivity" was ranked as the highest priority among all the criteria as listed in Table 4. It has an RII value of 0.875. It is considered as the most important parameter for effective project planning and control. The second highest criterion was ranked as "Safety features" with an RII value of 0.873. It is a very close runner-up. This shows its high importance in the sustainability criteria. It also depicts that the respondents from construction industry are now more concerned toward the human well being and safety of personnel. The second runner-up is the "Ownership cost" of the equipment having RII value of 0.865. Ownership

Table 4
Ranking criteria for the selection of construction equipment.

Sustainable selection criteria	RII	Ranking by category	Overall ranking	Importance level
A. Socio-economic criteria				
S_E1: Ownership cost	0.865	2	3	H
S_E2: Operational cost	0.858	3	4	H
S_E3: Safety features	0.873	1	2	H
S_E4: Availability of local skilled operator	0.848	4	7	H
S_E5: Operator health	0.829	5	12	H
S_E6: Operator proficiency	0.819	6	14	H
S_E7: Training needs for operator	0.817	7	15	H
S_E8: Operator view and comfort	0.785	8	23	H-M
S_E9: Relationship with dealer/supplier	0.765	9	27	H-M
B. Engineering criteria				
$E_{ng}1$: Equipment productivity	0.875	1	1	H
$E_{ng}2$: Spare parts availability	0.865	2	3	H
$E_{ng}3$: Equipment efficiency	0.860	3	5	H
$E_{ng}4$: Easy repair and maintenance	0.848	4	7	H
$E_{ng}5$: Equipment reliability	0.846	5	6	H
$E_{ng}6$: Equipment capacity	0.843	6	8	H
$E_{ng}7$: Equipment operating life	0.841	7	9	H
$E_{ng}8$: Meet job/operational requirements	0.841	7	10	H
$E_{ng}9$: Fuel efficiency	0.836	8	11	H
$E_{ng}10$: Compliance with site operating conditions	0.819	9	14	H
$E_{ng}11$: Equipment age	0.817	10	15	H
$E_{ng}12$: Implement system	0.804	11	17	H
$E_{ng}13$: Machine/equipment standardization	0.797	12	19	H-M
$E_{ng}14$: Versatility of equipment	0.790	13	21	H-M
$E_{ng}15$: Control and information system	0.785	14	23	H-M
$E_{ng}16$: Structure and suspension system	0.775	15	25	H-M
$E_{ng}17$: Traction system	0.770	16	26	H-M
$E_{ng}18$: Meet haul road condition	0.765	17	27	H-M
$E_{ng}19$: Power train system	0.760	18	28	H-M
C. Environmental criteria				
E_n1: Energy saving	0.836	1	11	H
E_n2: Quantity of particulate matter	0.826	2	13	H
E_n3: Greenhouse gas emissions	0.817	3	15	H
E_n4: Oil/lube leakage control	0.817	3	15	H
E_n5: Fossil fuel consumption	0.814	4	16	H
E_n6: Noise control	0.802	5	18	H
E_n7: Environmental statutory compliance	0.795	6	20	H-M
E_n8: Vibration control	0.787	7	22	H-M
E_n9: Use of sustainable fuels	0.778	8	24	H-M
E_n10: Use of biodegradable lubricants and hydraulic oil	0.775	9	25	H-M

cost is the expenditure incurred by the contractors for acquiring the equipment. It is mainly comprised of first capital investment, interest, insurance, taxes, license fee and other expenditures. It has been found from the ranking analysis that among the top 25 criteria, seven socio-economic criteria, twelve engineering criteria and six environmental criteria have been rated as "High" priority indicators by the respondents. In terms of their average RII, socio-economic criteria have RII 0.844, engineering criteria RII 0.841 and environmental criteria scored RII 0.818 respectively.

Apart from "High-Important" criteria, the remaining 13 criteria were grouped into "High-Medium" importance scale. This includes two socio-economic criteria, seven engineering criteria and four environmental criteria. On an average, "High-Medium" RII value for socio-economic criteria is 0.775, engineering criteria is 0.777 and environmental criteria is 0.783. The important criteria of these category are: S_E8: Operator view and comfort and S_E9: Relationship with dealer/supplier, $E_{ng}13$: Machine/equipment standardization, $E_{ng}14$: Versatility of equipment, $E_{ng}15$: Control and information system, $E_{ng}16$: Structure and suspension system, $E_{ng}17$: Traction system, $E_{ng}18$: Meet haul road condition, $E_{ng}19$: Power train system, E_n7: Environmental statutory compliance, E_n8: Vibration control, E_n9: Use of sustainable fuels, E_n10: Use of biodegradable lubricants and hydraulic oil. The above listed criteria have determined the ranking of sustainable indicators for the selection of onsite mechanized construction equipment. It has been established based on above analysis that all sustainable criteria were ranked with "High" or "High-Medium" importance level.

5.3. Factor analysis

Factor Analysis is an analytical technique. It is used as data reduction technique in the literature. It was used by the researchers to develop the structure and inter-correlation among the decisive factors (Norusis, 1993). This technique is different from the ranking analysis in a way that it helps the researchers to find variation among the group of variables. The total percentage of variance shown by each of the variable is calculated which determines the number of factors for the whole set of data (Akadiri and Olomolaiye, 2012). Similarly, Factor Analysis can also help to form pattern matrix from a large number of variables which shows how different variable work together (Chan et al., 2004). The Factor Analysis has a validation requirement before it is being applied on a group of variables. In this respect, a validity test was proposed by Kaiser (1974) which is based on the range of eigenvalue. According to Kaiser (1974), any eigenvalue less than 1 is not suitable for the Factor Analysis. In this research, SPSS package was used to conduct Factor Analysis through two stage procedure which includes factor extraction and Varimax rotation.

The Factor Analysis results for the socio-economic criteria are presented in Table 5. Kaiser–Myer–Olkin (KMO) measure for this group of data is 0.891 and Bartlett's sphericity ($p = 0.000$) is significant. As the KMO is larger than 0.5, hence the sample data are suitable for the analysis. Two factors are extracted from the observed socio-economic variables that accounted 63% variance for Life Cycle Cost (LCC) latent factor and 12% variance for Social Benefit (SB) latent factor. The extracted latent factors are satisfactorily consistent as the factor loading is greater than 0.5. Secondly, the eigenvalue for both of the factors is also greater than 1.0. The LCC factor consisted of two economic items whereas SB factor comprised of seven items that focused on human and social aspects of sustainability consideration in the acquisition of mechanized construction equipment. Table 5 can also be viewed as a pattern matrix which highlights the correlation between the variables and latent extracted factors. This correlation is generally known as factor loading and represents the bonding strength of observed variable with the latent factor. The higher the loading, the greater will be the bonding and vice versa.

Table 6 shows the factor loading for engineering criteria. Here, both the KMO measure for sample adequacy (0.908) and Bartlett's test ($p = 0.000$) are significant. It has been observed that all of the factor loadings are greater than 0.50. From the pattern matrix, three factors are extracted from engineering criteria after Varimax rotation. These latent factors are performance, system capability and operational convenience and have 76.3% cumulative variation. These results show that extracted factors are consistent and their corresponding loading is appropriate.

The results for the factor analysis of environmental category are shown in Table 7. In this group, KMO measure for sampling adequacy is 0.905 and the Bartlett's test of sphericity ($p = 0.000$) is significant. Thus, the extracted factor i.e. environmental impact is appropriate and loading is in high range (as most of them are greater than 0.7). It has been observed that only one factor is extracted from this category. So, Varimax rotation is not applicable here. Overall percentage of variance for twelve items is 74.8%.

Table 5
Factor structure for socio-economic criteria and Varimax rotation.

Items for socio-economic criteria	Extracted factors	
	Life cycle cost	Social benefits
Ownership cost	0.903	
Operational cost	0.863	
Operator view and comfort		0.872
Operator proficiency		0.858
Training needs		0.852
Operator health		0.847
Availability of skilled operator		0.796
Relationship with supplier		0.723
Safety features		0.715
Eigenvalue	5.667	1.140
Percentage% of variance	63.078	12.670
Cumulative% of variance	63.078	75.784

5.4. Meaning of underlying factor analysis

5.4.1. Life 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

Table 6
Factor structure for engineering criteria and Varimax rotation.

Items for engineering criteria	Extracted factors		
	Performance	System capability	Operational convenience
Equipment efficiency	0.785		
Equipment capacity	0.778		
Equipment productivity	0.775		
Equipment reliability	0.756		
Equipment operating life	0.731		
Fuel efficiency	0.591		
Equipment age	0.529		
Structure and suspension system		0.899	
Power train system		0.863	
Traction system		0.825	
Implement system		0.769	
Control and information system		0.757	
Machine standardization		0.629	
Easy repair and maintenance			0.754
Meet job and operational requirements			0.740
Spare parts availability			0.653
Compliance with site operating conditions			0.645
Versatility of equipment			0.630
Meet haul road conditions			0.616
Eigenvalue	11.972	1.494	1.036
Percentage% of variance	63.013	7.862	5.453
Cumulative% of variance	63.013	70.875	76.328

Table 7
Factor structure for environmental criteria and Varimax rotation.

Items for environmental criteria	Extracted factor Environmental Impact
Oil and Lube leakage control	0.908
Use of biodegradable lubricants and hydraulic oil	0.906
Quantity of black smoke emissions	0.894
Fossil fuel consumption	0.869
Use of sustainable fuels	0.856
Greenhouse gas emissions	0.852
Energy saving	0.842
Noise control	0.840
Vibration control	0.838
Environmental statuary compliance	0.830
Eigenvalue	8.986
Percentage% of variance	74.884

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.

5.4.2. Performance

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.

5.4.3. 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).

5.4.4. 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.

5.4.5. 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.

5.4.6. 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.

6. 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.

Appendix A. Questionnaire Survey on Development of Sustainable Crietria for the Selection of Onsite Construction Equipment

The purpose of this questionnaire survey is to prioritize the factors required for the selection of sustainable construction equipment in onsite mechanized practices. Your kind assistance is required to evaluate this criterion on a five point Likert Scale. The outcome of this research endeavour will directly benefit the contractors in selecting construction equipment in terms of techno-economic, socio-economic and environmental constraints.

Please give your feedback either by fax/email/postal-mail at your convenience.

Address: Civil Engineering Department, Universiti Teknologi PETRONAS, 31750 Tronoh, Perak, Malaysia. Fax: 05-3656716, Email: alwaris2002@yahoo.com

Section I: Background & General Information

Please fill in the blanks and tick [✓] in the options as provided.

1. Name of Company:____
2. Position in Company:
   - ☐ Project Manager ☐ Quantity Surveyor
   - ☐ Construction Manager ☐ Equipment Manager
   - ☐ Manager ☐ Others:
   - ☐ Engineer
3. Respondent's experience in construction projects? _____(Years) _____ (Months)
4. Please mention your level of education:
   ☐ Bachelor ☐ MSc/MBA//Master ☐ PhD ☐ Others_____________
5. What is the age of your organization?
   ☐ < 5 years ☐ 6 – 10 years ☐ 11 – 20 years ☐ > 20 years
6. What is the size of your organization you work in?
   ☐ < 100 staff ☐ 101 – 250 staff ☐ 251 – 500 staff ☐ > 500 staff
7. Your experience in infrastructure projects? _____(Years) _____ (Months)
8. What type of infrastructure projects do your company specialize in? *(You may select more than 1 options)*
   ☐ Ports ☐ Railway ☐ Dams & irrigation ☐ Bridges ☐ Roads & Highway
   ☐ Tunneling ☐ Airports ☐ Pipelines ☐ Others: _____________

Section II: Sustainable Selection Criteria for Onsite Mechanized Equipments or Machineries

9. Please rate your opinion on a 5 point likert scale on the following criteria in term of their importance in the selection of onsite mechanized equipments and in relation to the sustainable categories under which they are listed.

Criteria	Extremely Important	Very Importan t	Neutral	Low Important	Not at all Important
	5	4	3	2	1
A. Economic Criteria					
1. Ownership cost	☐	☐	☐	☐	☐
2. Operational cost	☐	☐	☐	☐	☐
B. Engineering Criteria					
1. Equipment age	☐	☐	☐	☐	☐
2. Equipment capacity	☐	☐	☐	☐	☐
3. Equipment reliability	☐	☐	☐	☐	☐
4. Equipment efficiency	☐	☐	☐	☐	☐
5. Equipment operating life	☐	☐	☐	☐	☐
6. Equipment productivity	☐	☐	☐	☐	☐
7. Fuel efficiency	☐	☐	☐	☐	☐
8. Implement system	☐	☐	☐	☐	☐

9. Traction system	☐	☐	☐	☐	☐
10. Structure and suspension system	☐	☐	☐	☐	☐
11. Power train system	☐	☐	☐	☐	☐
12. Control and information system	☐	☐	☐	☐	☐
13. Compliance with site operating conditions	☐	☐	☐	☐	☐
14. Meet job/operational requirements	☐	☐	☐	☐	☐
15. Meet haul road condition	☐	☐	☐	☐	☐
16. Versatility of equipment	☐	☐	☐	☐	☐
17. Easy repair and maintenance	☐	☐	☐	☐	☐
18. Machine /equipment standardization	☐	☐	☐	☐	☐
19. Spare parts availability	☐	☐	☐	☐	☐
C. Environmental Criteria					
1. Greenhouse gas emissions	☐	☐	☐	☐	☐
2. Fossil fuel consumption	☐	☐	☐	☐	☐
3. Energy saving	☐	☐	☐	☐	☐
4. Noise control	☐	☐	☐	☐	☐
5. Vibration control	☐	☐	☐	☐	☐
6. Quantity of particulate matter	☐	☐	☐	☐	☐
7. Oil/lube leakage control	☐	☐	☐	☐	☐
8. Use of sustainable fuels	☐	☐	☐	☐	☐
9. Use of biodegradable lubricants and hydraulic oil	☐	☐	☐	☐	☐
10. Environmental statutory compliance	☐	☐	☐	☐	☐
D. Human and Social Criteria					
1. Availability of local skilled operator	☐	☐	☐	☐	☐
2. Operator health	☐	☐	☐	☐	☐
3. Operator view and comfort	☐	☐	☐	☐	☐
4. Safety features	☐	☐	☐	☐	☐
5. Operator proficiency	☐	☐	☐	☐	☐
6. Training needs for operator	☐	☐	☐	☐	☐
7. Relationship with dealer/supplier	☐	☐	☐	☐	☐

10. Is there any other additional criteria/information with respect to Question No. 9 to enhance this study?

A. Economic criteria:

____

B. Engineering criteria:

____

C. Environmental criteria:

____

D. Social criteria:

____

11. Name of Respodent *(Optional)*:

____

12. Email:

____

Thank you very much for your time and participation.

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